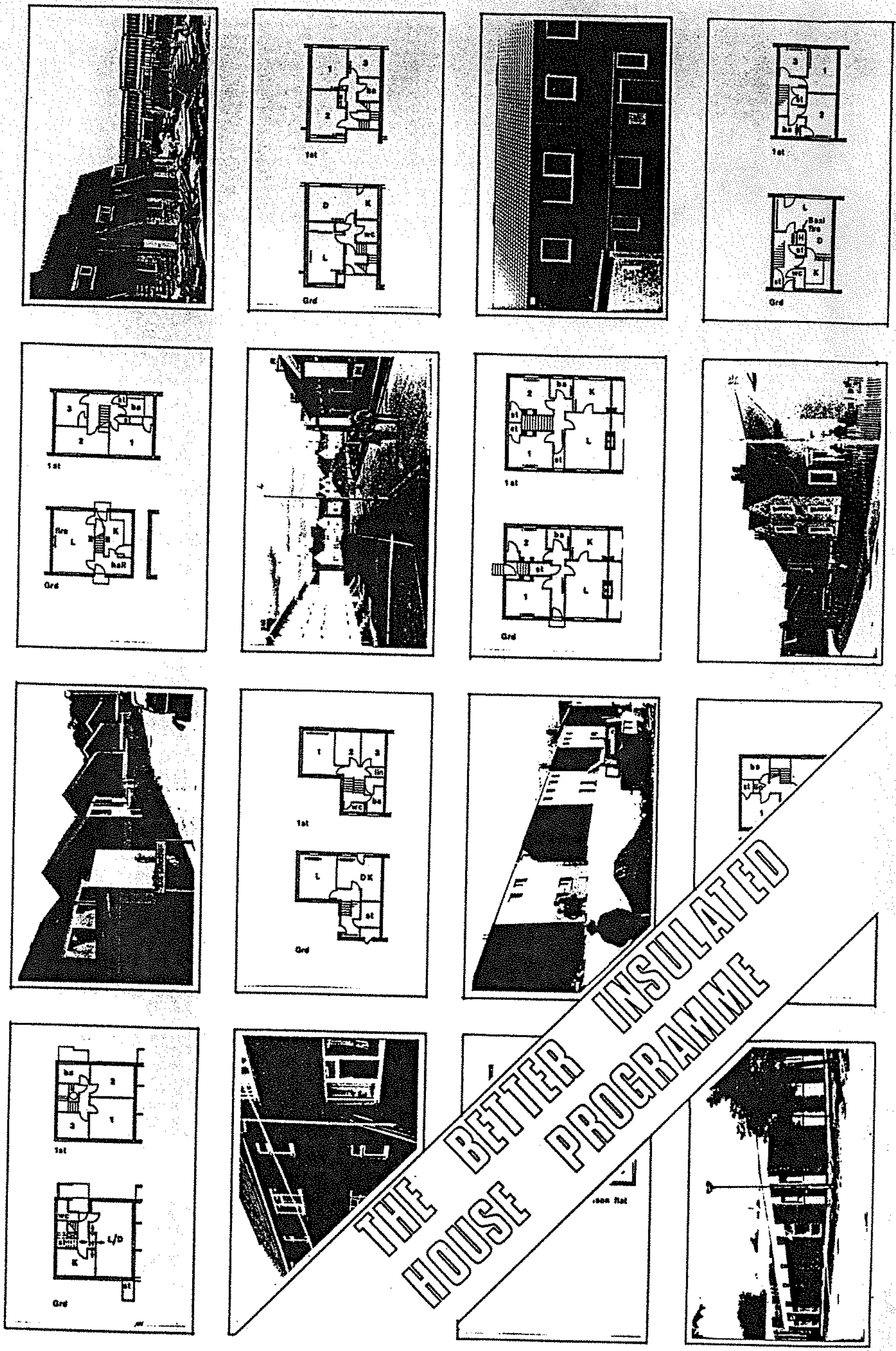
THE BETTER INSULATED HOUSE PROGRAMME



THE BETTER INSULATED HOUSE PROGRAMME

OMNIBUS REPORT

Prepared by

THE JOHN OSBORNE ENERGY CONSULTANCY

for

THE DEPARTMENT OF THE ENVIRONMENT

(Draft 1: April, 1984)

Ref. 1750

TABLES AND FIGURES

A. MANAGEMENT SUMMARY

1. Background
2. Principal Results and Conclusions

A. SUMMARY

1. BACKGROUND

1.1. The Better Insulated House Programme was conceived in 1973 in awareness of the imminent world shortage of fuel which would in time affect its price. Its purpose was to explore the energy saving potential in practice of measures to reduce energy consumption in housing.

1.2. The Programme has aimed to monitor the effects of incorporating higher standards of thermal insulation in occupied dwellings, so as to:

(a) Measure realised energy savings in practice

(b) Identify technical risks

(c) Note users' reactions.

The first of these required priority attention to provide much needed evidence about the cost-effectiveness of insulation.

1.3. The first project, started in 1974, was a new scheme at Coventry. As concern for energy conservation increased, the programme was expanded to a further eight projects covering both existing and new building. It was recognised that the programme would take some years to complete. The findings have provided evidence for the increase of thermal standards in the Building Regulations, and for a trend towards the thermal upgrading of the existing stock.

1.4. As the Programme proceeded, more data have become available, to better explain the performance in use of well insulated houses, their heating systems and the control of heat within the dwelling. This information is relevant to achieving the optimum benefit from insulation. It became clear that better thermal insulation changes the behaviour of buildings, particularly in a retrofit context. Improved understanding of this altered performance can optimise energy savings. For these the Programme has yet further been broadened and some additional studies incorporated: some have involved physical tests, others paper studies of collected data. Physical studies include further air infiltration tests, and the measurement of gas boiler efficiencies. Studies of the data include estimates of incidental heat gains and of mean ventilation rates (Appendix H).

1.5. Though the Programme as such is finished, work is continuing on certain aspects arising from it, mostly under other funding, in particular that of SERC. The chief participants are the University of Wales Institute of Science and Technology, British Gas Corporation and Heriot Watt University. The subjects of these further analyses include the performance in use of gas heating systems, natural ventilation and internal air movement, the usefulness of incidental heat gains and socio-economic means of predicting energy consumption. Data from other projects are also being analysed in increasing depth, by DOE. All this could provide further insights into the results recorded in this Report.

1.6. During the last few years, techniques for monitoring have advanced Pand methods of analysis have improved to match the more complete data. Lessons have been learned from others working in this field, in particular the British Gas Corporation (Watson House), the Building Research Establishment, the Birmingham School of Architecture and the National Building Agency. The result has been the completion of the (somewhat ambitious) tables of figures in Section B.1, including varying degrees of extrapolation to account for the incompleteness of source material from the earlier projects.

2. PRINCIPAL RESULTS AND CONCLUSIONS

Realised Savings

2.1. Higher U values of 0.6 for walls and 0.35 for roofs were tested in the Programme. They reduced overall heat losses by between 21 and 36% (including estimated ventilation losses) compared with the matching control houses at each project.

2.2. Realised savings ranged from 1 to 41% of the space heating fuel consumption, comparing the average of Test and Control houses - worth between £1 and £80 annually, at Spring 1982 tariffs. The capital cost of the building improvements ranged from £60 to £180, on the basis of the same improvements carried out to 'normal' housing of the same type and construction, in Autumn, 1980.

Temperatures

2.3. Whole house daily average temperatures, averaged for each sample group, ranged from 12.9degC up to 19.4degC. Most households have a morning heat-up to a modest temperature only, followed by a slow climb to an evening peak. It was very rare for houses to be heated overnight. Reasons for the large differences between sites in apparent comfort standards must be speculative.

2.4. On the whole, it seems that percentage improvements in insulation were rewarded with broadly similar percentage reductions in space heating fuel consumption. In addition to these fuel savings, most of the better insulated (test) houses had become warmer.

2.5. Nevertheless, two of the eight projects were far adrift from this generalisation, sufficient to require explanation. To a degree all projects differed, and the reasons are important. Such explanations are a vital part of the overall conclusions of the study.

Percentage expressions of fuel saving can be misleading as it is the quantity of fuel saved or its money value which matter. The Report was strongly criticised in draft for this practice. However, % figures are still commonly used as they are more easily grasped and can be applied to a (known) present consumption, wherever the size and form of the dwellings and their other energy uses are comparable.

Factors affecting project differences

2.6. (a) In most projects the Test houses became warmer than the Control houses. These increases could have been partly voluntary (more comfort) but in most cases could have been for want of the means or knowledge to prevent it. In the sense that one group had on average higher whole house temperatures than the other, like was not being compared with like. This difference ranged from 2degC down to zero. At Abertridwr the temperature difference was reversed - control houses being warmer - hence yielding a very high realised saving.

(b) Although the Test dwellings used less fuel than the Control dwellings, the savings would have been significantly increased if the temperatures had remained the same. The fuel cost of even a small rise in temperature can be very high - £46 for electric heating and £19 for gas, per annum, on average of the BIH projects. Often, by minor modifications to a house or its heating system, temperatures could be better controlled. Such modifications ought always to be considered along with insulation measures. They might include adjustments to heat distribution or curtaining the staircase.

(c) In all dwellings, space heating is substantially assisted by 'incidental heat gains', from body heat, cooking, electric lights and appliances, solar gains and from the hot water system. At Plymouth for example these made up 49% of the total heat input of the Control houses, and 50% of that of the Test houses. Comparable figures for Darlington are 41/47%, and a mean of 25 case study houses in Birmingham 46%. For larger or detached houses this proportion would be lower. As these gains are the same (in quantity) irrespective of insulation, increased insulation tends to reduce the balance of heat required by the heating system by a far bigger proportion than that by which heat losses have been reduced by it.

Simplified Results Table

2.7. Table A.1. is a simplified presentation of Project results. (This Table is further expanded, with explanatory text, in Section B.1).

Technical Risks

2.8. The possibility that technical hazards might accompany increased insulation standards was explored and showed that some risks may exist. Associated work has corroborated this finding. Understanding these hazards and their implications for quality of construction will be necessary to avoid possible building failures from improved thermal insulation in all housing. These matters are discussed in detail, with illustrations, in Sections B.3 and B.4. There is a good case for site testing of completed new houses to ensure that builders learn how to achieve high standards, particularly or airtightness and of the completeness of insulation.

Factors affecting economic conclusions

2.9. The results achieved possibly understate the potential for Building Regulations change:-

(a) In new houses at the proposed standards of insulation, heating systems size could be smaller (and rather cheaper) thus enhancing the cost-effectiveness of the insulation. The Abertridwr project is particularly relevant here, demonstrating that a less extensive system is appropriate to a well insulated house, and where the overall house temperature is a little lower (though still acceptable) than for a whole-house system, makes for outstanding cost-effectiveness.

Different forms of heating might be considered, in order to reduce cost (e.g. individual convector or radiant/convector heaters rather than the conventional and costly piped system).

(b) Estimates of construction cost, used in assessing the cost-effectiveness of insulation standards likely to be adopted as mandatory, contain uncertainties. On the one hand commercial competition and technical advances may lead to cheaper solutions, but on the other the need to avoid technical risks may call for some extra expenditure.

(c) Recent studies have pointed to a shortfall between theoretical and achieved performance for many conservation measures. The difference has been described as 'Realisation Factor'. This can be influenced by both <u>workmanship and design,</u> both of which should in time improve, and lead to somewhat better savings.

Conventional controls do not usually control well enough to make conservation measures perform as well as is desirable.

(d) It seems likely that some, usually older, gas <u>boilers</u> were not working as <u>efficiently</u> as they might, especially in the better insulated 'Test' houses; hence new projects with heating systems matched to the insulation ought to be somewhat more efficient and economical for that reason.

(e) Family Expenditure Survey data indicates that the tenants of BIH project estates had below average incomes. If it were marginally the case that poorer households spend less on heating, then average households should spend more, and insulation save them more. However, among the BIH estates, low income did not always go with low energy expenditure. Where the fuel cost was relatively low and the 'energy need' high (as with young families at home all day) heating standards were relatively high, but the dwellings themselves are mostly quite economical to heat, and the less compact and well-insulated ones of the older stock may be different (cf BIH Hamilton project). Hence it cannot be concluded that an <u>application of these standards</u> to either new housing or the existing stock <u>will not necessarily save more energy.</u> It would be likely to save more, however, on average.

Outstanding Technical Issues

2.10. The projects drew attention to the importance of <u>ventilation control</u> in houses which tend at present to be excessively leaky, especially after initial structural settlement and shrinkage have taken place. In well insulated houses with small heating systems, the ventilation system is especially important as air movement affects the distribution of heat and the possibility of achieving economical comfort. Ventilation clearly needs to be arranged to minimise the risk of condensation and pollution. Figure 3.2 shows the size of ventilation heat loss in comparison with fabric loss, for a well insulated house.

2.11. Evidence, particularly from one site, drew attention to the increased importance in low energy houses of the heat absorbed and stored in concrete floor slabs and party walls. Where intermittent heating is the preferred regime - BIH temperature profiles showed this to be so - 'standard' U-values for floors/party walls are inapplicable. They should be designed in an understanding of their storage function; some floor insulation would normally be required, placed under the slab so the latter can absorb solar gains.

2.12. The various low energy test houses employed a range of heating and control systems. Those in use showed that conventional heating and control hardware are often inappropriate to these kind of houses. Whole systems in general and room emitters in particular tended to be too big, too crudely controllable, or in some cases simply redundant. The material and labour cost of distributing heat through copper pipes hardly seemed justified by the heat needed, and natural convection would do, even if such rooms were to need supplementary heating once in a while. Even in retrofit projects there is sometimes a case for a more radical approach to the choice of heating, where the opportunity arises.

Impact on householders

2.13. Because energy scarcity is primarily perceived by householders in terms of annual costs, energy uses have been studied in detail, to determine the financial gains from insulation in the context of the total annual 'fuel bill' - including energy used for purposes other than space heating. Trends in energy use and the movement in relative prices of fuel both affect comparison at 1982 prices, the average saving over all projects was at about 9% on annual energy costs. This is not all - it is equally important to look for the savings from the energy used for hot water, electrical appliances and lighting, since these constitute a substantial proportion of the annual cost.

Technical Summary

2.14. Well insulated houses are different in kind from conventional ones, and will not realise there full energy saving potential unless designed and detailed accordingly. Their heating systems and controls must be designed to match. Incidental heat gains, which usually make a major contribution to heating, should be utilised to the maximum extent. There should be a trade-off, in capital cost between insulation and heating plant. There will sometimes be a case for increasing the insulation to make the most use of this opportunity, especially in cases where thicker insulation is relatively cheaper (per unit of thickness). Such considerations may occasionally lead to very high levels of insulation in combination with only minimal heating, and this is used very little. Tightness of construction and controlability of ventilation would then be essential.

2.15. In all houses, insulated to or above test standards, the control of temperatures is vitally important. Simple, foolproof, easily understood means are best.

General Summary

2.16. The Programme has shown that insulation works, and that fuel savings from the modest measures tested are justifiable in economic terms. Hence the measures tested were adopted as mandatory for new houses, as from April 1982. Where steps can be taken to control temperatures, the savings will be greater.

2.17. For existing houses, such measures may be adopted voluntarily by some, but the savings to be made will usually be modest in comparison with total annual energy bills. Rewards will improve as fuel prices rise; if temperatures are fully controlled, and if savings are also made in energy for hot water and for lighting and household appliances.

2.18. If the savings realised from the average of BIH projects were repeated over the 20 million dwellings of the existing stock the total saving should be some 0.5million tons of coal equivalent - out of a national total of primary energy consumption for all purposes of 300 mtce.

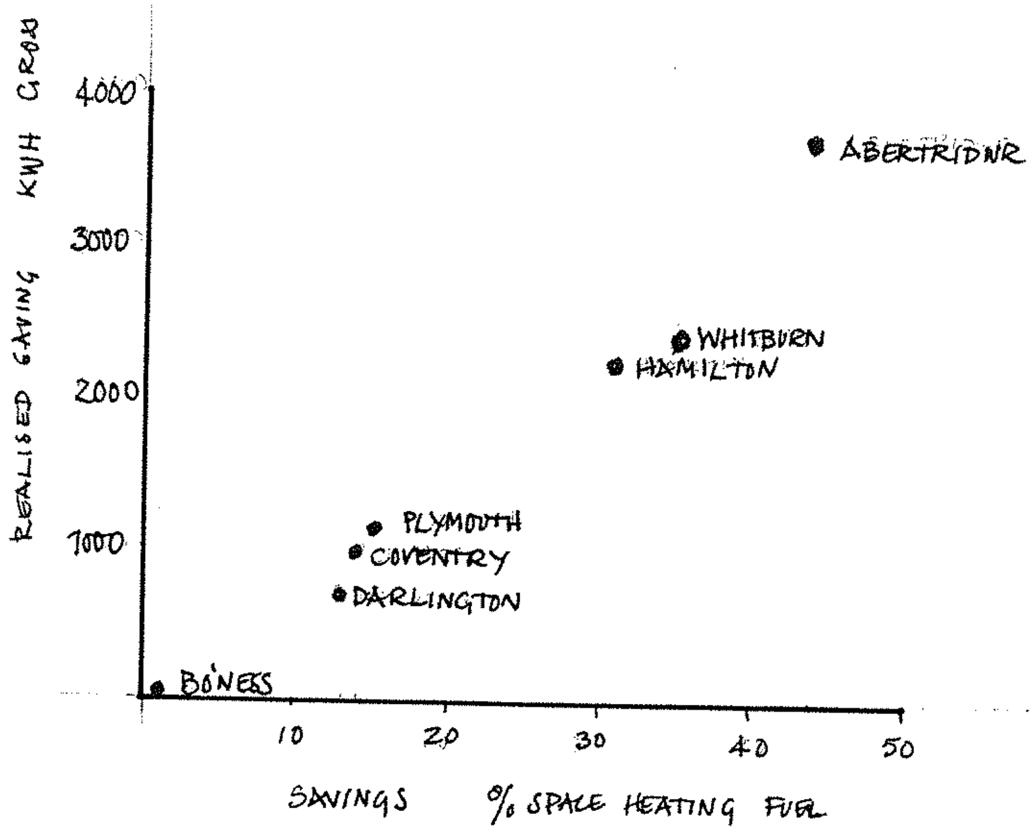
TABLE A.1. - SUMMARY OF PRINCIPAL NUMERICAL RESULTS

Project	Heating	Calculated Heat Loss Watts/ degC Test/Ctrl	Reduction % loss	Average Household Test/Ctrl	Seasonal Space Heating KWH net Test/Ctrl	Realised Saving KWH Gross	Value of Saving 1981/82	Saving % of Space Heating Fuel	(Control) Total Annual Energy Costs 1981/82	Insulation Costs March 1982	Mean External Temperature degC	Mean Internal Temperature Test/Ctrl
WHITBURN 4p houses	GF only, ELu/f or st rads, EL DHW	163/253	-36	3.7/ 3.7	4340/6700	2360	£80	35	£436	£216	6.3	14.4/12.9
HAMILTON 2-3p flats	Gas rad, LR fire, Gas CH elsewhere, 'Stat in Hall, Gas DHW	180/250	-28	3.1/ 2.3	4945/7161	2216	£32	31	£290	£103	6.3	16.7/15.1
PLYMOUTH 5p houses	GF only gas warm air, 'Stat in LR, EL DHW	199/264	-25	4.9/ 4.0	6152/7269	1117	£16	15	£356	£267	8.3	17 /15
DARLINGTON 1-2p flats Single glazed	EL ceiling heating, LR EL fire, EL DHW	89/119	-25	1.2/1.3	2402/3069	667	£31	13	£244	£ 53	7.5/6.9	17.3/15.4
COVENTRY 5p houses	Whole house gas boiler/ rads, LR gas fire, TRV's	186/223	-17	5.5/5.2	5760 / 6900	1148	£18	17	£372	£ 83	4.5	19 /17.8
Double glazed	Test Houses	156	-30	5.0	5910	990	£16	14		£267		18.4
WASHINGTON 5p houses (no control group)	EL panel rads in all rooms. Room & house 'Stats EL DHW	192/-	NA		3750	-	-	-	£398	NA	5.7	14.5/ -
ABERTRIDWR 4p houses	Gas boiler/ rads (cont whole house, test partial) Gas DHW, 'Stat in LR TRV's	192/268	-28	3.6/ 3.7	4782/8490	3708	£68 + £13 rates	44	-	£230 -1265	6.0	17.3/19.4
BO'NESS 6p houses	EL Storage/ warm air, LR 'Stat, EL DHW	264/335	-21		8412/8448	36		1	-	-	-	-

FIGURE 1.1. COMPARISON OF REDUCTION IN THEORETICAL HEAT LOSS RATES WITH ATTAINED SAVINGS IN SPACE HEATING ENERGY CONSUMPTION

Figure 1.1.

Comparison of Reduction in Theoretical Heat Loss Rates with ~~Attained~~ Savings in Space Heating Energy Consumption.



B. RESULTS

SECTION ONE

ENERGY USE AND SAVINGS

1.1. Space Heating Energy

1.2. Other Energy

1. ENERGY USE AND SAVINGS

1.1. Space Heating Energy

1. Table 1.1 shows the 'principal' results. Part A contained a condensed version of this. The free use of the expression 'estimates' does not indicate a shortage of measured data. It arises from the nature of task. For data of this sort to answer all the relevant questions fully, it is necessary to construct from it equations describing the flows of energy into and out of the dwellings for a whole heating season, (or at least a clearly defined period for several months, for which the data are complete). Through instrument failures certain gaps and inaccuracies inevitably occurred in the data, making this task impossible and thus necessitating careful extrapolation of available data.

2. Columns 1 to 7 of Table 1.1 show the basic information about each site. Column 1 gives the location (town name) together with a figure for published Degree-Days of the Zone in which the site stands for September-May inclusive of the winter for which other data for that site have been tabulated. This figure provides a crude comparison between the sites, of their relative coldness, considering also the differences between windows. The mean external temperatures of column 17 are more reliable in respect of a site, as opposed to its Degree-Day Zone. Degree-Days are a cumulative count, calendar monthly, of days and mean daily temperatures below the 'base' level of 15.5degC. (These are published continuously by D.En).

3. Column 2 identifies the overall period by calendar date within which the monitoring took place. Usually this is a calendar year, and occasionally more. For the sake of analysis however a shorter period was selected for study, usually around a heating season and sometimes less depending on the availability of data. This period of intensive monitoring included that of internal and external temperatures, which are crucial to the analysis of data from site temperature data being the most difficult to collect this tended to be in shortest supply. Where temperature data was missing, various forms of extrapolation were used to fill in gaps.

4. Column 3 is either a record or an estimate on the length of heating season as apparent from consumption data for the winter in question. 'Heating season' is difficult to define in any circumstances. Houses within each group vary. Weekly external temperatures rise and fall such that heating is used or not used in response to daily whims of weather, over a transitional period of several weeks. Households differ, too, in their response to outside temperature, such that within any one sample group the heating season actually operated may vary within a range of several weeks. It is usual to study the principle heating system and ignore the possible use of supplementary heating (e.g. electric fires), so that where supplementary heating is used, the season 'reckoned' is less than truth. Where the supplementary fuel is electricity, it is impossible to separate this from other uses of electricity. In 'all-electric' dwellings, the same difficulty is found in attempting to estimate space heating input, except where separate meters were installed. This was not done at Darlington, but in this case the weekly monitoring of consumption allowed the beginning and end of the season to be

identified fairly confidently. (See Figure 2.4).

There is not much difference between sites in the lengths of their heating seasons. Hence Plymouth, with the least number of Degree Days, has nevertheless a long season because spring and autumn are long and fairly cool. The Heating Season is determined by the period when outside temperatures are below the Equilibrium Temperature for the house - product of its rate of heat loss and the Incidental Gains available. Theoretically, better insulation should shorten the Season, but in practice this does not always happen, viz. Darlington where habitually higher inside temperatures made for a higher Equilibrium Temperature and hence (column 3) a longer season for the Test Dwellings. The Seasons quoted for Coventry and Abertridwr were merely limited by the availability of complete data. Heating Seasons in Scotland tend to be culturally or economically determined, as in many summers outside temperature seldom rises above that which in more Southerly places would be regarded as warm enough for heating not to be needed. The crucial factor is probably sunshine, which saves most energy when the outside air is relatively cool and its heat is therefore needed.

5. Column 4 describes the heating and DHW (domestic hot water) system at each site. The most important difference between projects is the expense of heating - whether Ground Floor only or full house. The location of a governing thermostat (where present) is noted, and this is significant in relation to the response of each group of houses to the increased insulation.

6. Column 5 gives the heat loss rate (per degC inside/outside temperature difference) for each of its sample groups, three in the case of Coventry. This is derived from measurements of the houses and knowledge of their construction and house U-values. It also incorporates estimates of ventilation heat loss, based on assumed air change rates. The latter may however be very inaccurate (it is exceedingly difficult to measure) and even U-values may be rather different from their theoretical levels for a variety of reasons (e.g. rain soaking of walls, excessive radiant heat losses, gaps in insulation or in masonry construction etc). Hence the rate of loss for a house may be in reality more or less than that predicted by conventional calculations, which are in any case somewhat simplified - assuming all types of brick are alike, and ignoring cold bridges, for example. Given fairly reliable data about fuel consumption, incidental heat gains, and temperatures, it is possible to 'calculate backwards' and arrive at the revised estimate of the overall heat loss rate. This was done for Plymouth, for example, and suggested that the two groups of houses seem to have realised rates of 255 and 350W per degC for Test and Control groups respectively, as against 199 and 264 as calculated. In this case the excess loss could well have been attributable to higher ventilation rates due to their exposed site. The Coventry project appeared to 'fall off' in performance between the first season, where results seemed to show very good fuel savings for the test houses, and the later period recorded in this table where the data were more complete. If this observation is correct it might be explained by increased air leakage as a result of the shrinkage of timber, as occurred for certain at Abertridwr. Such a thesis might be proved by 'calculating backwards' if this were possible. In this case it is not because the Coventry data set in the table is 'incestuous'

- i.e. the estimates for incidental gains were arrived at via other data, rather than independently, and hence are not a reliable source of cross-checking. This is an important consideration in deciding how much a project should be monitored, and where economies tend to be sought. Only by very complete monitoring can it be shown what performance has been realised by the insulation measured (including agression control) independently of disappointment due to increased temperatures.

7. Column 6 is a factor of the Test and Control heat loss rates, and expresses the 'degree of insulation improvement' attained. Insofar as the insulation (etc.) may in the event perform poorly, it were better if this percentage figure represented measured, as opposed to calculated, performances. We have not done so here, simply because most of the data are not sufficiently complete. Accurate or not this percentage figure has to stand for comparison with later figures for energy savings - though usually in a very simplified form to match lay comprehension. In the event, an average improvement in calculated heat loss rate of 26.25% seems to yield an average saving in space heating fuel of around 24%. These figures are conveniently close but a graph of all projects (Figure 1.1) shows how far from reliable the average relationship is. This graph makes it clear how potentially misleading are any assumptions for heating fuel savings based on the average yield on the number of projects.

8. Column 7 shows average sizes of household for each sample. All else being equal, highly populated houses should give better savings for insulation in terms of a proportion of heating fuel, though not in the <u>quantity</u> of fuel saved, since with the extra incidental gains (people, hot water, cooking) space heating consumption would be lower and more sensitive to a reduction in heat loss, though the influence of this factor is lost among other, greater effects. It might be argued that crowded houses will require more ventilation (more bodies, more cooking smells and water vapour), but the Coventry single glazed houses are the most populous group, and have average performance under this particular judgement.

9. Columns 8 and 9 represent <u>net</u> heat input space heating for the heating season (or monitoring period) at each project (i.e. for gas fired projects the figures incorporate an assumption about the energy lost in burning and represent the actual heat put in. The Coventry figures represent a 30 week monitoring period, and Abertridwr 16 weeks (about half a heating season). A glance down the columns revealed data reflecting the size and 'lossiness' of the buildings, their internal temperatures and the external climate of the period; it all seems to make sense.

10. Column 10 shows the 'saving', being simply the difference between the heat inputs of the average of each group, shown in the previous two columns, and column 11 the cash value of these savings at January '82 prices. (Gas at 27.2p per therm and electricity at 4.71p per unit for a simple supply of 3.4p for an equal mixture of On and Off - current - a convenient simplification). Note that the figures for Coventry and Abertridwr represent periods of 30 and 16 weeks respectively. By crude adjustment, the cash value figures can be written as £18 and £16 for the two Coventry test groups and £68 for fuel saved at Abertridwr for a whole year. To the latter can be added £13 per annum savings as a result of Rates being lower for the test

houses with their less extensive heating systems. This was a pleasing perk for the Abertridwr project, but it may be unwise to assume it will always apply for partially heated houses, since their lower heating costs (for acceptable room temperatures) should make them more desirable, and hence, theoretically, attract higher Rates (which Heaven forbid!).

11. Columns 12 and 13 record total metered energy consumptions for all fuels, as the basis for Column 14, which gives a total annual fuel bill, including standing charges but not maintenance. The figures for Coventry and Abertridwr are estimates for annual consumption based on the shorter period of monitoring in each case. Column 14 is significant in that it shows, set against column 11, how relatively small is the reduction in total annual energy costs achieved by insulation. The average of the latter for the projects in the table is £383, and the average annual cash saving £34 - less than 10%. This is not due to disappointing savings from the insulation (though these could have been better) but because other uses of energy than space heating tend to cost a lot, leaving space heating a small proportion of the total. There is of course scope for savings within some of those other uses, but nothing so simple as by thermal insulation of the building. The latter suffers by comparison with the former, such that to the normal non-logical householder the savings to be made seem mere peanuts.

12. Column 15 represents the cost of the additional insulation in each case, as it would be in the context of an 'average' housing scheme with the same size of houses and the same construction and materials. Hence for example the figure for Plymouth is high because the exposed site necessitated a particularly expensive cavity fill; a new-built project on the same site might well not have cost so much, as a cheaper, built-in fill could be used. The figure for Coventry is low because to increase the wall insulation in houses of timber frame construction is a cheap modification. The Darlington figure represents the cost of extra insulation to the standards applied to test houses in other projects. In fact the control block already had 100mm of roof insulation, and the test block already had cavity fill as well. All that was added to the project was double glazing, which would have cost more than the figure quoted but in terms of heat loss would have (roughly) balanced the extra roof insulation present in the control block, which in normal circumstances would not have been. For Abertridwr, two figures are given representing a lowest and highest figure in fact the project cost the highest figure this being attributable to the very high cost of dry lining as a wall insulation. The lower represents the cost for treating the same houses with foam cavity fill which is the cheapest form of wall insulation. In practice, a cheaper form of cavity fill, such as are now available, but were not then, might well have cost not very much more than the figure that we have put in for foam cavity fill. Finally for Bo'ness, no figure is yet available due to the progress of accounting after the contract.

13. Columns 16 and 17 represent external temperatures from the best sources available, for the period of the heating season (or the monitoring period). In some cases Met. Office data from the nearest Met. Station was used in lieu. Note that the Darlington figures show significant temperature differences between the two sites, albeit only four miles apart and close to the same river. Their sunshine records were different as well, so we concluded there was a genuine quirk of micro climate in operation. The Coventry temperatures seemed extraordinarily low - based on measurements at the site. This phenomenon was noticed at the time and great efforts made to check the accuracy of instruments and readings. No fault was found, so these temperatures must be accepted. Micro climate strikes again. How accurate then is Met. data as a generalisation about a whole region?

14. Columns 18 and 19 are house mean internal temperatures. The (sometimes quite large) differences between test and control groups are of note. Also the great differences between projects. Abertridwr is outstanding in that test houses were cooler, because of their less extensive heating systems - and this explains the enormous realised fuel saving in column 10.

15. The comparison of bedroom and living room temperatures is of interest. Such figures as are available are unfortunately not compatible with those in the table, but give an indication of this comparison for some of the 2-storey houses;

	Bedroom	Living Room
Whitburn		
Test	12.5	18.3
Control	11.1	17.0
Plymouth		
Test	15.2	18.9
Control	14.0	17.8
Coventry		
Test SG	19.5	19.0
Test DG	16.1	18.2
Control	18.7	19.9
Washington	13	15

In the context of a survey of house temperatures, BRE derived from spot-readings in a large number of houses a pair of formulae to estimate upstair temperatures, given downstairs ones, in both centrally heated and non-centrally heated houses.* Of the BIH projects noted above, Whitburn bedrooms were considerably cooler than the BRE survey would have suggested, while the test houses at Plymouth were quite close. Of the Coventry examples, the test double glazed houses fit the formula (for centrally heated houses) exactly, as do those at Washington. It should be noted that spot measurements of temperature are not accurately comparable with weekly average measurements (BIH) being always made during the day. However, downstair/upstair relativities should be similar, assuming the effects of night-time relativities have worn off by the time the household is willing to admit survey personnel.

* TU = 0.97 TD - 1.52 (centrally heated)
TU = 0.70 TD + 2.06 (non-centrally heated)
from Baldwin & Gidman BRE N127/81

16. Columns 21 and 22 show the mean for each sample group of the temperature <u>difference</u> through the season referred to. This is the difference between means of internal and external temperatures, and as such represents the extent of heating a house received, by whatever means. In combination with the relevant heat loss rates (column 5) this figure allows the calculation of a total seasonal heat loss - a grand total of how much warmer a house was than outside air during the period when space heating was used. Observe how the Mean Temperature Differences reflect both inside and outside temperatures; for example, the lowest figures are for Whitburn, a fairly cold place, and those for Plymouth which is far milder, are a little more, to provide for considerable warmer interiors. Coventry's were highest combining a low external temperature with very high internal ones. Note how the Abertridwr figures are reversed - test houses cooler.

17. Column 22 attempts to evaluate in fuel terms the amount by which test groups were warmer than control groups in most projects. It can be argued that this extra warmth should be included as a benefit in the cost-effectiveness calculations. But in most and possibly all cases, the Higher temperatures resulted from a natural change in the behaviour of the house in response to insulation, given that temperatures cannot be controlled room by room. This phenomenon and its consequences are discussed in Section 2.

18. Columns 23 and 24 are estimates, of varying degrees of reliability, of the <u>average</u> weekly contribution of all the available incidental heat gains. Some (Plymouth, Darlington, Coventry, Washington, Abertridwr) have been built up from separate estimates for each component source. Others were derived by the subtraction of space heating input from total heat gain (16 above) - or loss, which must be equal to gain. Estimating by subtraction ignores that another input factor is also unknown, that of ventilation loss. Ventilation loss is included in the column 5 estimates of heat loss rate (see 6 above).

19. Columns 25 and 26 are derived from column 8, but stated in 'average weekly' form, the comparison with columns 23 and 24.

20. Column 27 is the savings that would have been achieved were there no temperature rise, and no under performance of the insulation. Compare these with column 10, the realised savings.

21. Column 28 states this 'potential' saving as a percentage of the space heating fuel used in the control houses. For comparison, column 29 states the realised savings also as a percentage of control house heating fuel.

1.2. Other Energy

1. At the time the BIH Programme was started, there was an established belief, based perhaps on research sōme years old, that domestic energy tended to be apportioned, between uses, as shown in the left column of the following table. BRE have recently revised this table, as below.

Space Heating	64%	60%
Hot Water	22%	23%
Cooking	10%	9%
Appliances	4%	8%
	100%	100%

(both tables - delivered energy)

(Source BRE CP56/75) (1981 revision - unpublished)

2. As measured data has become available from the BIH Programme further significant revision to these assumptions has been shown necessary. Since it seems that:-

i. hot water use has increased;
ii. electric appliance uses have increased;
iii. space heating has become more efficient, and houses more compact;
iv. incidental heat gains have increased, at least compared with space heating, thus reducing the need for space heating;
v. electricity has become a lot more expensive, compared with other fuels (and because the present tariff differentials represent the cost of producing electricity, they are likely to stay).

(British Gas Corporation make the reservation that the above may be conditioned largely or wholly by a reduction in space heating, in their view).

3. The combined effect of these changes at the all-electric Washington project tabulates:-

Space Heating	30-35%
Hot Water	33%
Cooking	10%
Lighting and appliances	27-23%
	100%

4. Even here there is uncertainty because some space heating was drawn from appliance sockets.

These being all-electric houses, heating, cooking and hot water can only be quoted in 'useful units' (i.e. after conversion from fossil fuel). For gas, the equivalent conversion is done in the house (simple comparison would not be valid for the different fossil fuels) so gas figures are always more.

Comparable percentages for all-electric test houses at Bo'ness were:-

Space Heating	51%
Small Power	21%
Hot Water	19%
Cooking	7%
Lighting	2%
	100%

5. The Bo'ness houses were larger, and many of them detached, so naturally space heating was more than for Washington.

6. Figures from Coventry needed to be converted to reflect the efficiency of gas appliances compared with electric ones. Coventry test houses, expressed as useful units of energy, approximated to:-

Space Heating	53% (436 Th p.a. or 309 GJ)
Hot Water and Cooking	31% (300 Th or 189 GJ)
(Electric) lighting and appliances	16% (2500 kWh or 99 GJ)
	100%

Note:- GJ = Gigajoules, or units of 278 kWh. or 9.5 therms.

COST

7. The Coventry houses used gas and electricity as most househol and hence would have comparable costs, for isolated houses, amount this case to (annually, at January '82 prices):-

	Test houses £	%	Control houses £	%
Space Heating	119	33	181	42
HW/Cooking	82	22	82	19
Lighting and appliances	118	32	115	27
Standing Charges	49	13	49	12
	368	100	427	100
(Saving in test house			£ 59	14)

8. Gas bills frequently included an annual charge of about £17.60 for maintenance in addition.

9. The figures for Hot Water and cooking are reckoned largely at the higher rate charged for the first 52 therms per quarter, and space heating all at the lower rate. Neither hot water nor cooking were metered separately at Coventry, but an estimate of 300 th pa for both uses was provided by the local Gas Board. The total gas consumption for each group of houses were as measured. Electricity consumption indicated here was the mean annual figure for all houses not cooking by electricity, at the project.

10. These figures illustrate:-

the prominence of electricity costs in the total energy bill (more than space heating in the test houses)

the relatively small cost of space heating in these (very well heated) houses

the saving, between test and control houses, as a very small part of the total annual energy bill.

11. The first comment suggests that more attention should be given to electricity consumption as an important component of domestic energy. The other two go some way, in our view, to explaining the relatively small impact that house insulation has so far made on the public mind in the United Kingdom.

TABLE 1.1. PROJECT BASIC DATA

Column No. PROJECT	1 Degree Days	2 Monitoring Period	3 Season T/C (weeks)	4 Systems	5 Loss Rates W/degC T/C (calculated)	6 Improvement %	7 Average People T/C
WHITBURN 2/3p houses	2265	1.9.75 - 6.6.76	40/40	GF only El.u/f or s.rads El.dhw	163/253	- 36%	3.3/2.9
HAMILTON 2/3p flats	2265	1.9.75 - 6.6.76	40/40	G rad. LR fire Gas CH other rooms - stat in hall Gas dhw	180/250	- 28%	3.4/2.9
PLYMOUTH 5p houses	1965	2.2.76 - 30.1.77	38/40	GF only GWH - stat in LR El.dhw	199/264	- 25%	4.9/4.0
DARLINGTON 1/2p flats	2293	8.9.75 - 6.9.76	38/36	El.ceiling htg.LR El.fire El.dhw	89/119	- 25%	1.2/1.3
Single glazed	2073	25.10.77 -	30/	Whole hse gas boiler/rads dhw G rad. LR fire	186/	- 17%	5.5/
COVENTRY			30	TRV's test houses	223		5.2
Double glazed 5p houses		16.5.78	30/		156/	- 30%	5.0/
WASHINGTON 5p houses	2156	5.77 - 5.79	38/NA	El. panel rads all rooms room + house control El.dhw	192/-	NA	
ABERTRIDWR 4p houses	2008	23.9.80 - 24.8.81	16/16	Whole house gas boiler/ rads dhw (test houses part house) LR stat	192/268	- 28%	3.6/3.7
BO'NESS 6p houses	2397	12.79 - 12.80	NA	El. storage/blown warm air. LR stat dhw	264/335	- 21%	

T = Test
C = Control

Average
= 26.25%

TABLE 1.1.(Contd.)

Project	8 Net Heat Input (KWH) T	9 C	10 KWH saving	11 Value £J/1982	12 KWH elect/therms gas Total Annual Metered Fuel T	13 C	14 (Control) Annual Costs (all uses)	15 Insulation Costs £	16 H.Season (Mean ext. Temps.) degC T	degC C
WHITBURN	4340	6700	2360	80	E. 9540	E.11900	436	161	6.3	6.3
HAMILTON	4945	7161	2216	32	G. 400 E. 1685	G. 579 E. 1651	290	102	6.3	6.3
PLYMOUTH	6152	7269	1117	16	G. 395 E. 3058	G. 488 E. 3752	356	186	8.3	8.3
DARLINGTON	2402	3069	667	31	E. 4056	E. 4672	244	44	7.5	6.9
	5760		1140	18	G. 676*			60	4.5	
COVENTRY		6900			E. 2798	G. 741 E. 2423	372			4.5
	5910		990	16	G. 685 E. 3245			60 + DG	4.5	
WASHINGTON	3750	-	-	-	E.10815**	-	398	NA	5.7	NA
ABERTRIDWR	3348	5942	2594	68 (81)	G. 436 (Est.for 55 week season)	G. 703	NA	NA	6.0	6.0
BO'NESS	8412	8448	36	1	E.15491	E.16304	585	NA	6.4	6.4

All Cost Jan. 1982

E = Electricity(kwhrs)
G = Gas (therms)
* 30 weeks only
** 16 weeks only

TABLE 1.1.(Contd.)

Project	18 House Mean Temps T degC	19 C degC	20 Mean Temp. Diffs. T/C T degC	21 C degC	22 Fuel Value Temp. Rise KWH	23 Est. weekly Inc. Gain kWh T	24 kWh C	25 Mean Weekly Space Heating kWh T	26 C	27 Potential Saving kWh p.a.	28 % Saving Pot/Real P	29 R
WHITBURN	14.4	12.9	8.1	6.6	1643	115	115	109	168	3992	58	35
HAMILTON	16.7	15.1	10.4	8.8	1935	190.7	190.5	124	179	4140	58	35
PLYMOUTH	17	15	8.7	6.7	2540	211	212	154	182	3374	49	15
DARLINGTON	17.3	15.4	9.8	8.5	739	79	69	68	101	1006	33	13
	19.0		14.5*		1125	261		192		1356	36	17
COVENTRY		17.8		13.3			268		230			
	18.4		13.9		472	167		197		4020	65	14
WASHINGTON	14.5	NA	8.8**	NA	NA	254	NA	98	NA	3821	NA	NA
ABERTRIDWR	17.3	19.4	11.3	13.4		156	232	209	371	3821	45	46
BO'NESS												

* 30 weeks only ** 16 weeks only

TABLE 1.2. THE MAIN CHARACTERISTICS OF THE BIH PROGRAMME DATA

Site	Number Test	Number Ctrl	Date Built	Social Survey	House Types	Heating	Insulation Test Roof	Insulation Test Walls	Control Roof	Control Walls	Monitoring Dates	Monitoring Temp	Consumption Frequency	Construction
1 ABERTRIDWR	20	19	75-78	78.79	Terrace 4 app't	Gas rads Boilers: 16 Kw C 8.8 Kw T	100	22	50		78-80 Comp	All rooms 5 min. Water Outside data	5 min.	Brick Cavity Block
2 BO'NESS	19	23	77	78.79	Detached Semi Terrace Up to 5 app't	Electric Warmair Off Peak Test:reduced Output Heaters	100 (50 grnd. flrs)	34	50	22	78-80 Comp	All rooms 15 min. Outside data	15 min.	Concrete Solid
3 BRAMPTON	22	21	54	?	Semi 20T/ 19C/5 app 2T) 2C)6app	20T) 19C)Electric 2T) 2C)Oil	100	Cavity filled	25		75 Abandoned			Brick Cavity Brick
4 COVENTRY	20	20	75	76.77	Terrace 4 App't	Gas Rads Gas radiant C/R C'king G or E	100	75 Gable Cavities 10D/G	50	25	9/75-6/77 reduced 78 recorders	Rota 5 min.	Weekly	Timber Frame
5 DARLINGTON	32	24	68T 72C	76	Flats 1 & 2 App't (old people)	Electric ceiling + bars on peak	100	Cavities filled D/G	100		9/75 6/76 Logger	All rooms hourly Outside data	Meters weekly	Brick Cavity Block
6 HAMILTON	20	20	26 74R	75	'4 Block' 3 App't	18T)Gas 18C)Rads 2 Elec.strge 2 Coal fired	100	Cavities filled	50		74-75	All rooms 1 week	Meters Monthly (6) Quarterly (1)	Brick Cavity Brick
7 PLYMOUTH	20	18	65	75.76 77	Terrace 4 App't	Gas Warm Air + Elec. fires	25 Beads +75	Cavities filled	25 Beads		2/75-5/75 9/75-Reduced 9/76-5/77	Rota Outside data	Meters weekly	Brick Cavity Block
8 WASHINGTON	32		75	78.79	Terrace 5 App't	Electric on Peak + Radiant Water off peak Electric	100	100 Gables 50 DG	-	-	76-78 Logger	All rooms daily Outside data	Total + space heat + others weekly	Timber Frame
9 WHITBURN	27	29		75	Terrace Flats 1-4 App	Electric Underfloor or storage	125	Cavities filled	25		12/74 9/75	Rota Week	Meters monthly	Brick Cavity Brick

B. RESULTS

SECTION TWO

ENERGY CONSERVATION MEASURES

2. ENERGY CONSERVATION MEASURES

2.1. Performance

Basic criteria

1. There are 2 criteria for evaluating measures for energy conservation from the results of field tests:

cost-effectiveness - will it pay for itself
energy saving - does it realise its full potential saving?

If the true potential for energy saving is not considered, and compared with savings realised in practice, there is a risk of being satisfied with a measure that performs poorly simply because it scrapes through the relevant test of cost-effectiveness and missing the chance of improving its performance in future by more skilful application.

Means of expressing realised savings

2. The results of the field tests (Appendix A) expressed energy savings in 3 ways:-

(a) as a realised annual cash value (per house for the mean of each test group of houses compared with its control groups);

(b) realised fuel saving in kWh net.

(c) as a % of the space heating fuel consumption of the control houses.

'Cash value' expression

2a. This is simple to use in cost-effectiveness analysis. It has however distinct limitations and needs to be considered together with other factors.

(i) whether consumption at a site was high or low, compared with the national average (e.g. at Plymouth where the mild climate made for low consumption and hence relatively small savings);

(ii) the possibility that savings had been reduced by voluntary temperature increases - i.e. tenants had opted to forego some potential savings to buy more comfort.

(iii) the effect of the price of the fuel saved, which could, for an expensive fuel, lead to a misleadingly optimistic conclusion except as applied to identical circumstances (e.g. Whitburn where savings were realised largely out of on-peak electricity):

(iv) significant increases in fuel prices (in real terms):

(v) significant changes in the comparative prices of different fuels.

(vi) the possibility that savings had been reduced by involuntary temperature increases in the houses. Simple and cheap modifications to heating systems, controls, or the dwellings may have avoided or reduced these. Taking the original insulation and these modifications together, the whole might seem with hindsight to be a more cost-effective operation:

(vii) the possibility of a drop in boiler or system efficiency following insulation. The same insulation improvement might have yielded more saving had the heating system been better matched to it (as would be the case with new houses).

(viii) potential capital savings from smaller heating systems.

'Percentage' expressions

2c. This third way of expressing energy savings - as a percentage of some known consumption figure - is not directly applicable to cost-effectiveness analysis but does offer a way of relating realised saving to calculated 'heat loss saving', as a measure of how well the improvement has performed in practice. All the BIH projects fell short of their 'potential' i.e. the saving that would have been achieved had theoretical building performance been achieved, boilers operated at full efficiency, and room temperatures not risen. This combination of circumstances is extremely unlikely to occur in practice in its entirety, but in many cases it should have been possible to approach the potential more closely.

Incidental heat gains

3. These are one of the true heat sources in a house - the others being the heating system. The heat lost from a house is supplied from two sources - from the heating system and from 'incidental gains'. They include heat from:

bodies (metabolic gains);
solar gains;
the hot water system (net of waste to drains);
cooking;
other domestic appliances, and lighting.

The relative size of incidental gains

4. Analysis of data from the Programme has shown that for modern, compact family houses of the kind used as control groups, incidental gains provide 40-50% of the total winter heat requirement (Figure 2/1). This proportion might be even higher for a flat or a very well insulated house, such as our test group dwellings. It would be lower for larger or less well-insulated dwellings, more northerly ones, or those which are under-occupied - where the losses would be larger but incidental gains not necessarily so. It has not been widely realised that incidental gains are such a large proportion, a factor with some very significant consequences. A reduction of heat loss, due to insulation, achieves a reduction of the 'balance of heat required' during a heating season, to maintain the same temperatures as before. A large part of this requirement is provided by incidental gains, which will stay constant

irrespective of insulation, so the balance of heat to be provided by the heating system ought to have been reduced by a far bigger proportion than that by which the overall losses have been reduced (Figure 2/2).

The saving to be expected in theory

5. This reduction of the 'balance of heat required' is the saving which ought to be expected from the insulation, if only all the room temperatures could be kept exactly as they were before insulation and heating and houses were performing perfectly. Because such a condition is rarely fulfilled, there is often scope for further saving, possibly greater again than that realised in the monitored field trial. This scope is represented by the difference between the 'potential' saving and that realised in practice. It ought to be possible in many cases to realise some of this potential by modifications to the heating system or controls, or further modifications to the house - any of which would need to be assessed in the light of an estimate of its cost-effectiveness.

Cost of a small change in house temperatures

6. Another effect of relatively high incidental gains is to increase the proportional impact on Space Heating fuel consumption of a small change in internal average temperature, and similarly on a small change in the Degree Day total between years and Regions. This illustrates how important it is to keep temperatures under control and how easily the potential from insulation can be lost by a failure to do so. Table 1.1 showed the measured whole-house temperature increase of test over control houses at BIH projects, and a rough estimate of the cost of these increases all of which have to be provided for out of heating fuel. Accuracy is not possible at this level of detail, because measured temperatures are subject to instrument error, room temperature gradients, etc. and calculated heat losses 'as built' cannot be accurate. Columns 28 and 29 of Table 1.1 shows for comparison the saving actually realised in heating fuel, over a year, from house group averages of these projects. The shortfall indicates the potential 'unrealised' saving. In some of the case study descriptions set out in Appendix A it is suggested what modifications might be made at certain projects to win back some of these unrealised savings. It would be of great value to test these suggestions in practice. It would of course be most unlikely for the full potential savings to be achieved.

Shortening of the heating season

7. It has long been believed that one of the effects of improved insulation is to shorten the heating season (Figures 2.3 and 2.4). This is a function of incidental gains, because with a reduced rate of heat loss the heating needs of the house are satisfied by incidental gains alone until later in the Autumn and from an earlier date in the Spring. Early analyses suggest that at Plymouth the heating season of the test houses was as much as 7 weeks shorter, but at Darlington, two weeks longer (see Appendix A). Hence more analyses must be done to reach a conclusion about what is most likely to occur in practice.

'Equilibrium temperature'

8. In calculations, the average external temperature will be lower during this shorter heating season, (Figure 2.4). In theory, a heating season can be assessed in terms of the period when an external temperature below which heating appeared to be needed in an average of the group of houses in question. The nearest that BIH data can approach to such a temperature is to identify the weekly average temperature of the coolest weeks in which no heating seems to have been used, either by individual dwellings or by the average of a group. This 'equilibrium temperature' is governed partly by the amount of incidental heat gains in the house. However, it has been observed, by others, that households tend to incur voluntary temperature rises.

Voluntary temperature rises

9. Some households voluntarily allow temperature increases, perhaps not realising that any such increases are at their own expense. It would be quite understandable for such increases to happen knowingly, where rooms had previously been uncomfortably cold and after insulation more warmth had been provided simultaneously with somewhat lower fuel bills. Where the measured temperatures of rooms in which the heat is controlled show no change between control and test houses, it can be argued that any increase in whole-house temperature is involuntary (e.g. at Whitburn). Where, as at Plymouth, test houses were warmer in 'temperature-controlled' rooms, it can be argued that such increases were voluntary. Were this the case, it would be reasonable to add to the 'realised fuel saving' from such houses the money value of this extra warmth. The combined values of fuel saved and voluntary extra warmth ought to count in cost-effectiveness calculations.

Uncertain factors

10. Such analyses can never be certain, since there has been no evidence that these increases were in fact either wanted or chosen. For example, changes in the balance of air and radiant temperature could 'fool' the thermostats and generate higher room air temperatures for the same settings. Alternatively the insulation might make for increased vertical temperature gradients within rooms and hence warmer air at the height of the recording censor. Again, the 24-hour average temperatures used in these calculations may be influenced by the slower cooling of cavity filled walls, even when there was no change in the temperatures maintained when the rooms were occupied. Such an increase in average room temperature may be of no practical benefit to the household unless they became aware of it and switched the heating off sooner. In general, neither the data nor the instruments were accurate enough to end speculation on this topic. Further analysis might help, but does not at present seem worthwhile.

Boiler efficiency

11. Another factor needing consideration was the efficiency of gas boilers. It is now widely recognised (e.g. Institute of Gas Engineers Communication 1105, Nov.1979) that most gas boilers fall off in efficiency at an accelerating rate, when working at a small proportion of their full load. Hence, where test and

control dwellings have identical boilers and the test dwellings have significantly reduced heat losses, the latter would consequently yield less energy saving than it ought.

2.2. POTENTIAL IMPROVEMENTS

1. In Appendix A it is suggested how factors specific to each project probably influenced the energy saved. - In hindsight based on general analyses of data and some theoretical work it seems it might have been possible to save more energy at little extra cost.

Potential importance of application of insulation measures

2. This is perhaps the most important new proposition to arise from the analysis of BIH data. It suggests that if certain rules were applied in the application of insulation to houses, considerably better results ought to be obtained. Three conditions of this are:-

(i) that any modifications necessary are economically justified by results

(ii) that they do not induce unwelcome side effects (e.g. condensation in bedrooms);

(iii) that they are acceptable to the households.

Causes of poor results

3. The projects pointed to features of house thermal performance which seem to have led to less savings than might have been expected. These are:-

(a) uncontrollable heat movement within the dwelling;

(b) increased time - lag of the structure;

(c) 'thermostat simplicity';

(d) crudeness of controls;

(e) fall in boiler efficiency after insulation.

All but (d) caused uncontrollable temperature increases calling for higher fuel consumption: apart from (c) there are practical modifications that may be effective.

Heat movement

4. It is of course well known that warm air rises. The commonest applications of partial (i.e. ground floor only) central heating systems in a two-storey house, rely on this - with warm air generated downstairs to finding its way upstairs to partially warm the bedrooms (Figure 2.5). This has long been regarded as an acceptable means of bedroom heating for the vast majority of British homes. Now the demand is for more than this. From the simple laws of physics it is known that the temperatures of bedrooms in such houses will be determined by the balance between heat supplied from downstairs and heat lost from upstairs to outside (Figure 2.6). Hence, all other things being equal, a house with better insulated walls and roof will enjoy warmer bedrooms. Where this bears on the design and size of heating systems is discussed in Section 3.2. But because it constitutes a change in the thermal behaviour of a house as a

the room whose temperature controls the heating system is insulated to the same degree (in terms of heat losses) as the whole house or

the system of heat-distribution through the house can be, and is adjusted so as to ensure that for each room, reduced losses are balanced by a reduced supply of heat. (With radiator systems, thermostatic valves fitted and set before insulating should achieve much of this reduction simply and automatically, within their limitations).

9. At another, quite separate, project there has been clear evidence of this phenomenon in reverse. The living room of a flat, heated by ducted warm air, was double glazed. The thermostat in that room responded to compensate, and reduce system output to the whole house, so other rooms became a little colder The tenant was advised to adjust the warm air registers, which he had hitherto never touched in all the years he had lived there. (EIK Project in The City of Birmingham and monitored by the Birmingham School of Architecture).

10. Similarly, any house controlled by a living-room thermostat should have a whole-house temperature rise reduced by double glazing the living room only, or otherwise improving its insulation.

Increased time-lag

11. Both the Whitburn and the Plymouth projects recorded a discernable increase in the 24-hour average temperature of living rooms, all or part of which can be attributed to the slower cooling of the filled cavity walls (Figure 2.8). This phenomenon is likely to have an impact on average temperatures without necessarily making any difference either to the household or to the total heat losses of the house. It will benefit the household only insofar as they may then be able to switch heating on later to achieve a given comfort level at the time required. For example, if the house cools considerably more slowly, it may be warmer first thing in the morning at the time heating is switched on.

12. In this sense the insulation serves to delay somewhat the dispersal of heat accumulated during the evening, though not long enough to be of practical use. The slight increase in 24-hour average temperature represents heat saved to no useful purpose - a proportion of the benefit of insulation that can never be realised except insofar as there may be more mornings when heat is not required. Thus there is no practical cure to this phenomen.

Boiler efficiency

13. Gas boilers tend to be at their most efficient at full load, and less so as the load decreases. It is quite difficult and extremely expensive to test boiler efficiency in an occupied house. This is currently being done, in the Abertridwr project (as well as elsewhere on a lesser scale), but the results will not shed light on the part that this factor may have played in the results of other BIH projects where it may possibly have led to reduced energy savings. Recent theoretical papers have indicated that at the Hamilton project if not elsewhere, there

result of improved insulation it is also relevant to the present Section. This poses the question as to whether there is evidence of a practical nature to suggest that this change of what could be effectively avoided, in order to improve the energy saving performance of wall and roof insulation.

5. The University of Bristol have studied internal heat transfers and, among other things, concluded that mass air movement is their chief vehicle, greatly exceeding conduction through internal elements of structure.

6. Subsequently HDD studied living-room and bedroom temperatures from the Plymouth project in relation to outside temperatures. This study showed for both test and control houses a range of amounts of heat transferred for the given living-room and bedroom temperatures. This suggested that the tenants have in practice considerable control over upstairs temperatures, presumably via control flaps on warm air outlets, one of which is in the hall, and also by the opening of room doors. Also, the test house bedrooms could reach higher temperatures than those of the control houses, for a given outside temperature, being a reasonable comfort level (15.5degC) in quite cold weather (2degC). The degree of control achieved commends an enclosed or curtained staircase to provide it in a more foolproof way (than by the opening or shutting of five or six doors) and this feature needs to be tested in practice. In doing so condensation risk must receive due attention.

Limitations of whole-house thermostat

7. In an insulated house, the whole heating system is controlled by a single thermostat, the energy saved is conditioned much by the reaction of that thermostat to the room in which it is located. The <u>mechanism</u> is once again the movement of heat within the house, but the driving force is the behaviour of the heating system in respense to its controls, and remedial action might be designed accordingly. (Figure 2.7).

8. The Plymouth project showed this dramatically. Here, the insulation measures achieved a reduction of about 22% in whole house heat losses. However, the thermostats were in the living rooms which had relatively little external wall, and quite large windows, with a consequently lower heat loss of only about 8%. So, to maintain the same temperatures in these rooms, the thermostats call for only 8% less heat than before. Heat is then supplied pro rata to the rest of the house, whose temperatures rise accordingly. In practice the situation will seldom be so bad, for two reasons. Firstly, the living-room loses less heat to other rooms in the house insofar as their temperatures rise, and hence the heat called for is reduced further than from insulation. Secondly, the supply of heat to other rooms is frequently controllable independently of the temperature in the living room (even if their is only the one thermostat), and may on some occasions be adjusted to prevent those rooms overheating. But it must be appreciated that both of these reasons usually only apply insofar as other rooms do overheat, and hence waste energy. The insulation can only be expected to perform to its full potential if either:

reason.

14. The Hamilton data, offers no positive support to this thesis, as there are too many unknown factors. Theoretical estimates could be made but would always be open to question. It ought nevertheless to be a consideration in any insulation project, what proportion of the boiler's design load will be called on at various times during the heating season, and what these are likely to be after reducing the dwelling's heat requirement by insulation. Such estimates should be compared with a load/efficiency graph for that boiler to see whether any appreciable loss of efficiency may occur. Both hot water load (though only occasional) and incidental heat gains should be taken into account. Where it appears that an appreciable loss of efficiency is likely to take place, there are two options from which to choose:

i. improve the system efficiency by controls to reduce 'cycling' and/or other modifications to reduce flue losses.

ii. replace the boiler with a more suitably sized one at the first available opportunity.

Normally this sort of exercise can only be contemplated where several similar houses are involved, sufficient to justify the work of calculation. Where a new boiler is being installed in a house with improved insulation, reasonable care should be taken to ensure this is taken into account in sizing the boiler.

Crudeness of controls

15. This problem relates to means of controlling heaters with simple 'on-off' switches. The worst are radiant fires which tend to be used for quick-response localised warmth in a room with cold walls and perhaps large windows.

16 Until the whole structure has warmed up, which in some circumstances may never happen, the radiant glow will be necessary for comfort whatever the air temperature is. Hence, except in quite mild weather there may be far less energy saving than a reduction in heat losses would otherwise lead one to expect. (This may well have occurred at either or both of Whitburn and Darlington). Once the structure is warm however, the room is likely to overheat, to a wasteful extent. The cure is to introduce thermostatic controls. It is unlikely to be practicable for all bars of the heater, because an electric radiant fire that does not glow visibly when there is a current in the elements is potentially dangerous. Such an arrangement was introduced in the Washington houses as a later modification (see Appendix A.6 on Washington).

17. This problem is less significant where the radiant fire is used neither frequently nor for long periods. If used for topping-up other 'background' heating it tends to provide substantially more heat than is needed to make the room comfortable.

18. It was apparent at certain projects that the tenant's comprehension of their heating and its controls was often inadequate. In particular, it seems that thermostats are often

FIGURE 2.1. BIH PLYMOUTH PROJECT

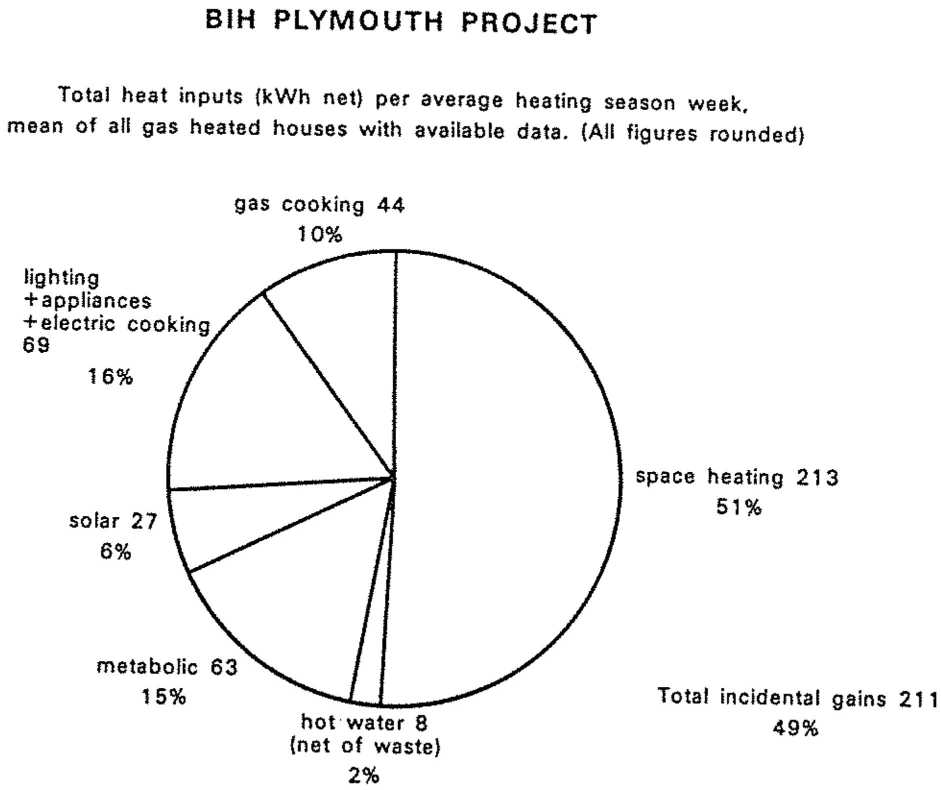


FIGURE 2.2. EXPECTED SAVINGS IN IDEAL CONDITIONS

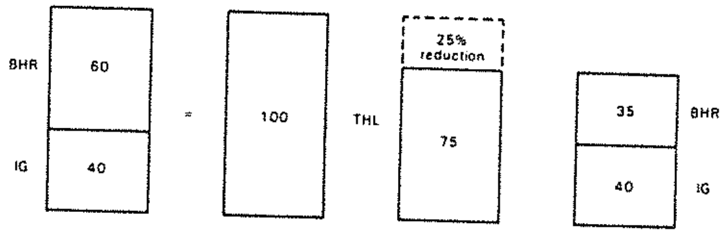
EXPECTED SAVINGS IN IDEAL CONDITIONS

Total Heat Losses = Incidental Gains + Balance of Heat Required (Heating fuel × system efficiency)

THL = IG + BHR

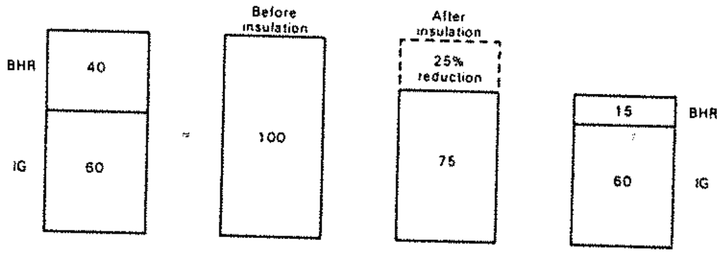
Examples:

a) IG = 40% of THL



In this case savings (in BHR) = $\frac{25}{60}$ = 41·7% of heating fuel

b) IG = 60% of THL



In this case, savings = $\frac{25}{40}$ = 62·5% of heating fuel

Notes:

1) These diagrams over simplify a little, since improved insulation tends to shorten the heating season, thus reducing the total IG available

2) All IG except solar and metabolic gains consume fuel, though in most expensive form, so it is cheaper in UK at present to use more of efficient heating system than to heat home from lighting and appliances. Trend will be for these to diminish with improved electric technology.

3) The IG figures are averages over a heating season and can not be used for design purposes.

FIGURE 2/3. PLYMOUTH:TEST/CONTROL GAS CONSUMPTIONS AGAINST EXTERNAL TEMPERATURE

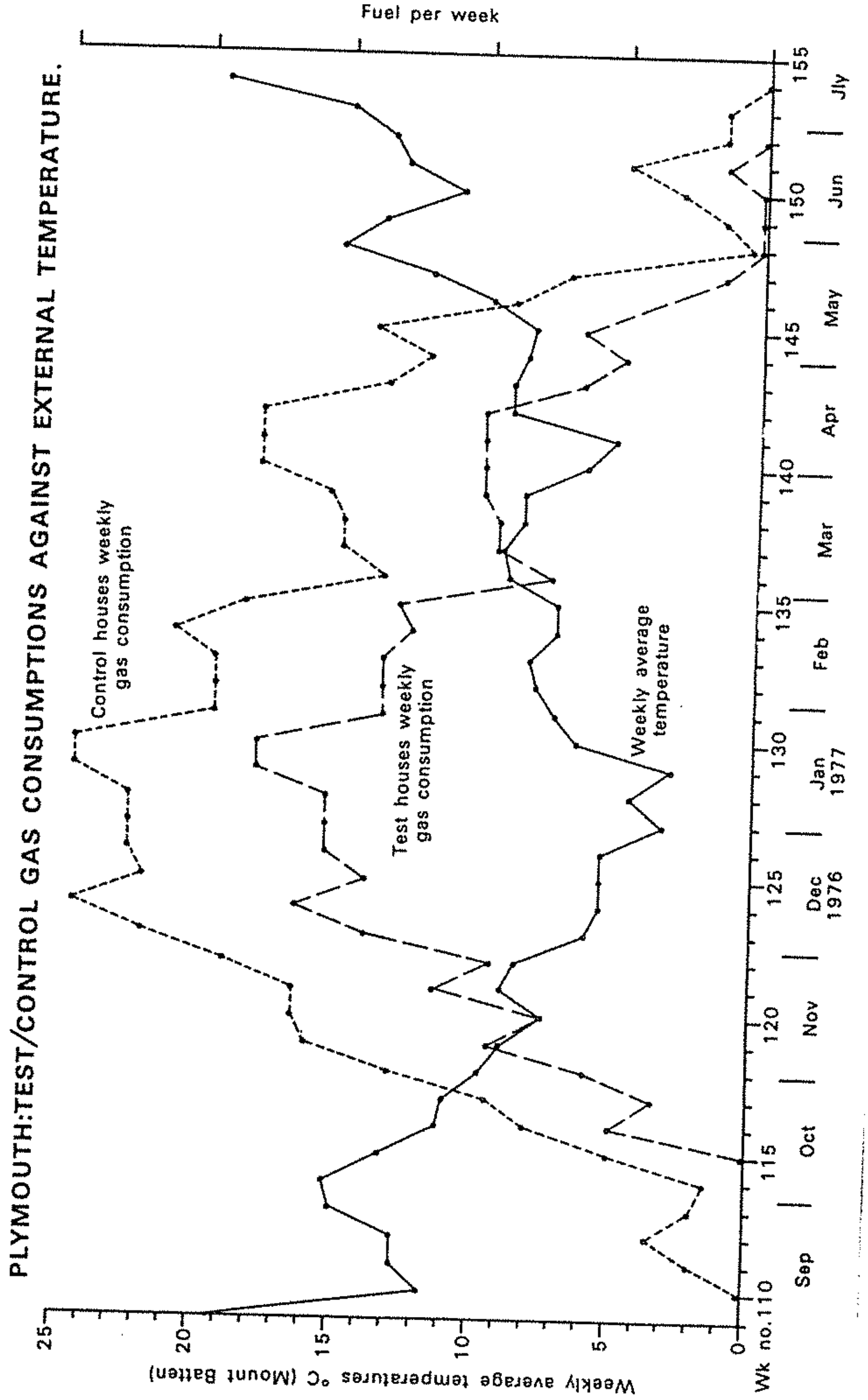


FIGURE 2/4. EFFECT OF HEATING SEASON LENGTH ON SEASONAL AVERAGE EXTERNAL TEMPERATURE

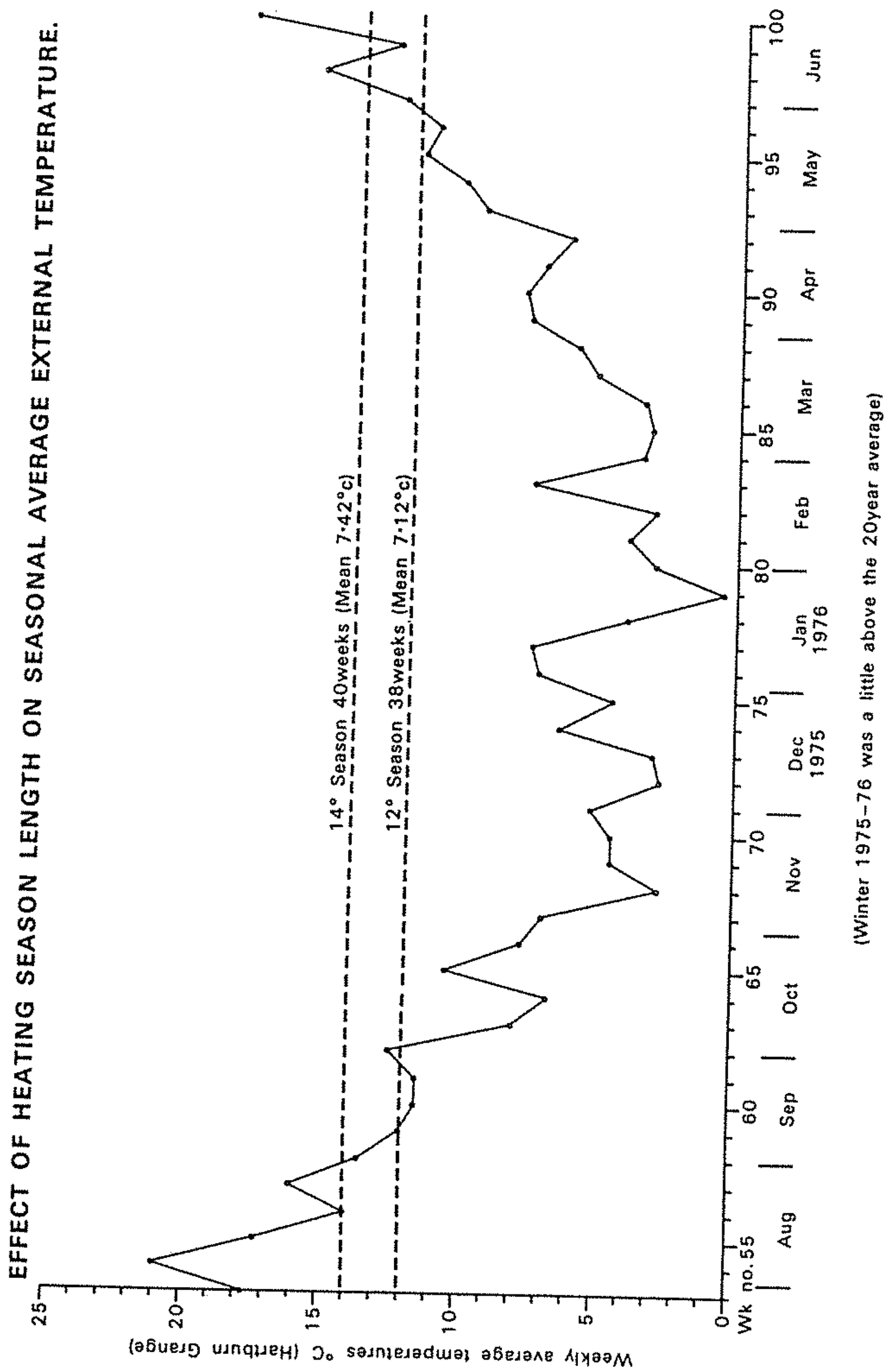
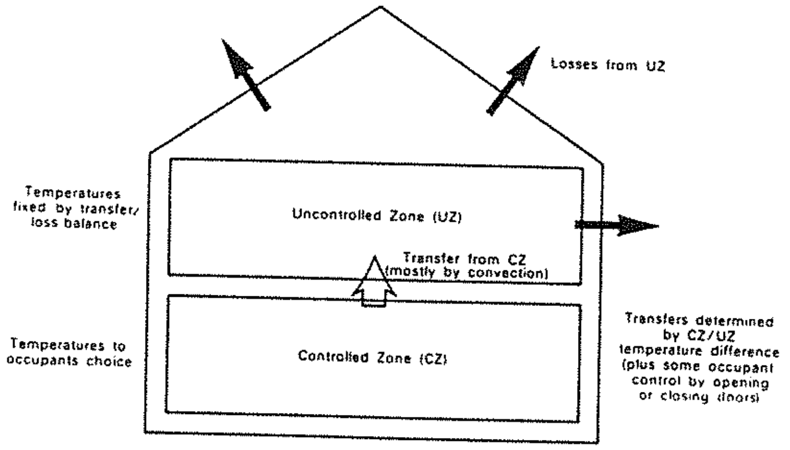


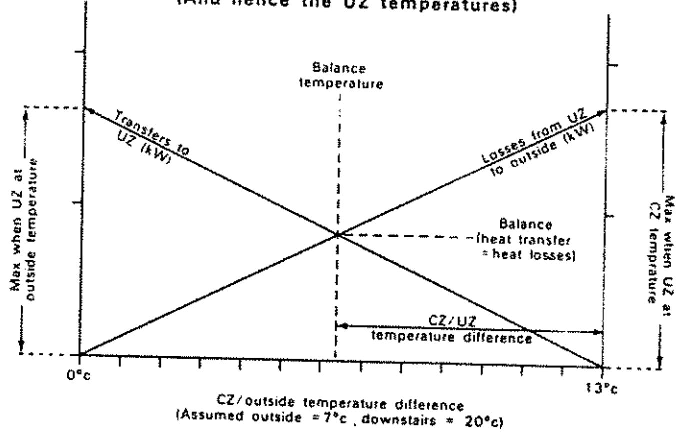
FIGURE 2.5. THE HEAT TRANSFER/HEAT LOSS-BALANCE

THE HEAT TRANSFER/HEAT LOSS BALANCE
(Partially controlled houses)



Note: Commonly the "controlled zone" is only one room and the rest of the house is "uncontrolled"

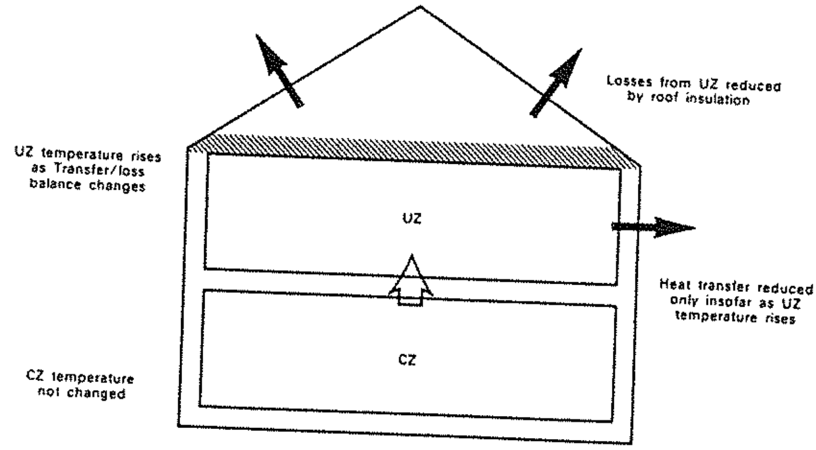
ESTIMATING THE HEAT TRANSFER/HEAT LOSS BALANCE
(And hence the UZ temperatures)



Note
In practice, heat transfer rate can reflect a "nominal U-value for the floor and stairwell" in the range 2-18 (warm air heated houses with air register in hall).
Upstairs incidental gains ignored. (See appendix J)

FIGURE 2.6. ROOF INSULATION TO A PARTIALLY CONTROLLED HOUSE

ROOF INSULATION TO A PARTIALLY CONTROLLED HOUSE



ESTIMATING EFFECTS OF 8·2a

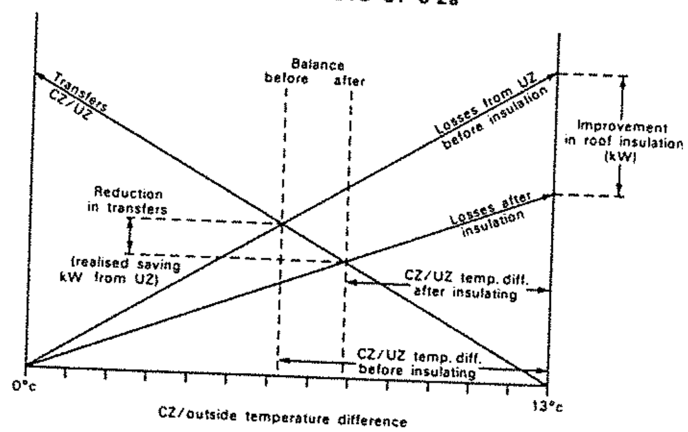
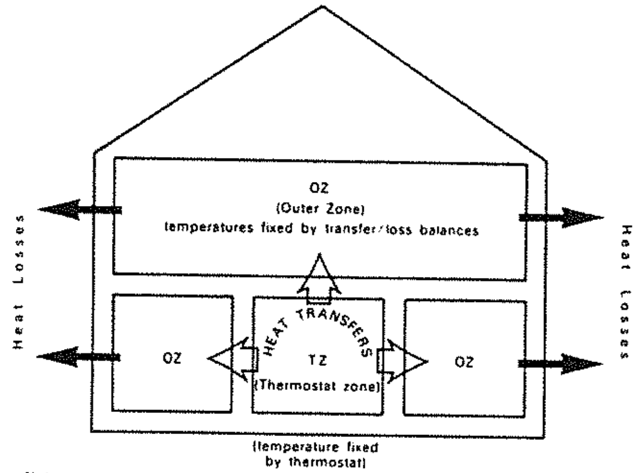


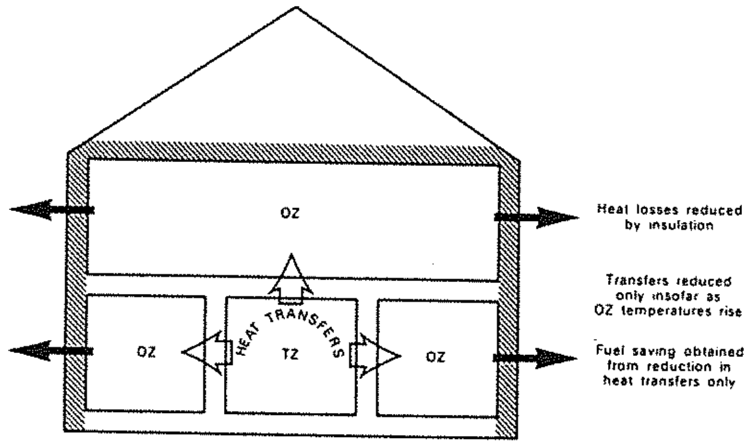
FIGURE 2.7. 'THERMOSTAT SIMPLICITY' BASIC MECHANISM

"THERMOSTAT SIMPLICITY"-BASIC MECHANISM



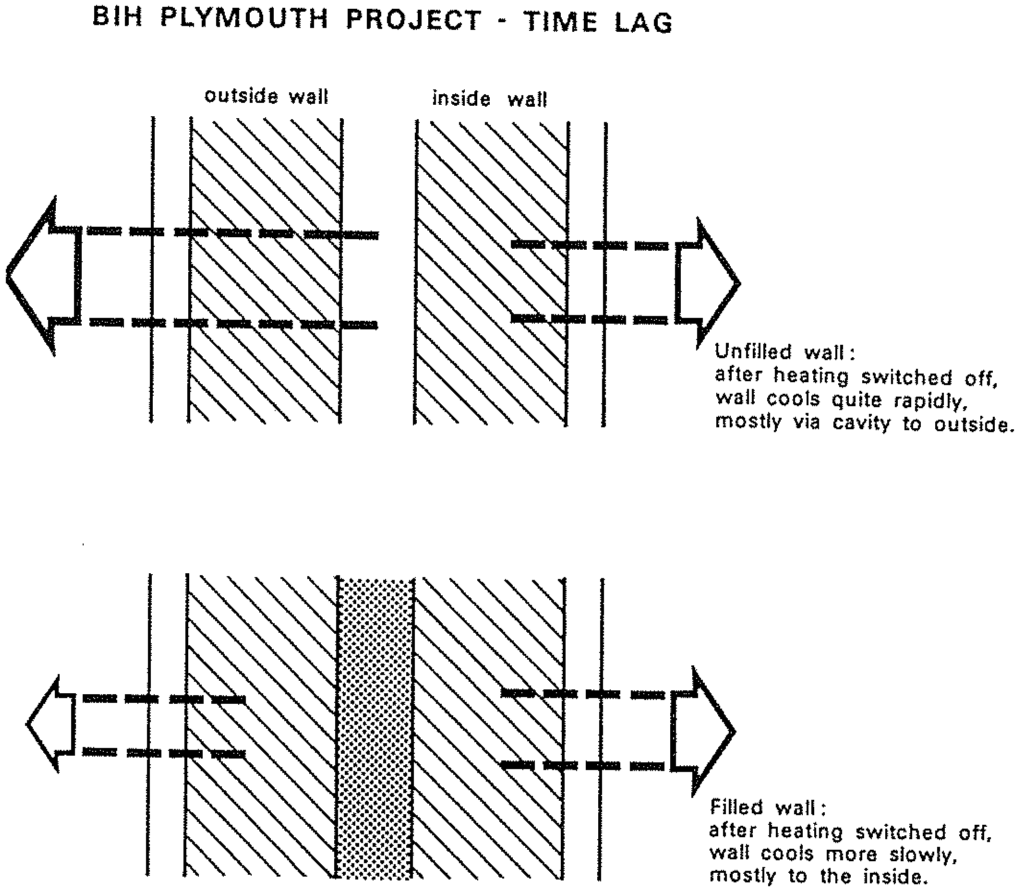
Note.
This is an unusual case where the thermostat is in an internal space, but the illustration is not complicated by direct heat losses from TZ to outside

"THERMOSTAT SIMPLICITY" WITH WHOLE-HOUSE INSULATION



Note:
Often heat is supplied direct to Outer Zone by radiator or air system, but is still controlled by central thermostat. In such cases the entire system responds in the same way ie. savings arise only insofar as transfers are reduced due to temperatures in OZ rising, unless distribution is adjusted.

FIGURE 2.8. BIH PLYMOUTH PROJECT - TIME LAG



B. RESULTS

SECTION THREE

IMPLICATIONS

3.1. Construction

3.2. Heating Systems

3.3. Ventilation

3.4. Problems

3. IMPLICATIONS

3.1. CONSTRUCTION

Background

1. An objective of the Programme was to be alert to possible technical hazards arising from the modified forms of construction necessary to reduce energy losses from dwellings. The Programme showed that the quality of craftmanship and site supervision were critical to obtaining the expected performance of the energy saving design. To obtain normally accepted workmanship the principle was adopted at the outset that no special demands were made on either craftmanship or supervision. Hence, any problems that occurred could be expected to recur regularly if the new forms of construction were widely practised, at least until new techniques had been thoroughly assimilated.

Design craftsmanship and supervision

2. Needless to say it is important that the design is right. But it is equally important that the designer understands what effect any departure from traditional building practice will have on the craftsman. With many energy saving forms of construction the basic techniques will have been worked out by the materials manufacturer, and are capable of overcoming most if not all detail conditions with little difficulty. But the craftsman will inevitably try to apply them as qucikly and conveniently as possible in the circumstances of the site, and may thus take seemingly minor decisions of his own, either varying the specification or perhaps omitting details of procedure which do not seem to him to be important. Such matters can escape the eye of supervising staff, who may not themselves understand their significance, and who may be able to give individual craftsmen little more attention than is normally necessary with conventional construction. Minor departures from the specification will often be invisible a very short time after they are made, and may only be detectable afterwards by equipment too rare and expensive to be yet a normal part of the equipment of site supervision (e.g. infra-red thermographic cameras and air pressure test apparatus). It follows that in all aspects of the building work that every person involved will need to understand the objectives of the design and how they are to be realised. The following notes illustrate these issued by examples from actual buildings in the U.K. Legal considerations inhibit the naming of specific sites where workmanship was a factor.

Roof insulation and condensation

3. Condensation tends to occur in roofspaces. The moisture, if allowed to accumulate, can lead to mould growth and, without attention, to rot in timber and corrosion of metal fastenings. Some regions seem to suffer more than others, according to combinations of local conditions. Insulation laid over the top floor ceiling tends to worsen the condition a little, but experience has shown that this is a less important factor than some others (e.g. the climate of individual winters). See Appendix A/1, para 6. At another site there was no mould, but note was taken of the moisture content of structural timbers. These roofs already had permanent ventilation at the eaves. One or two houses only developed excessively moist timbers (i.e. more

than 20% mc), and these were ones where roof insulation had been packed into the eaves, thus preventing the free flow of ventilation air.

4. A related problem is the need to ensure that roof insulation properly covers the ceiling of the room below. If it fails to do so, condensation and mould growth may occur on the underside where the surface uninsulated becomes cold. The operative installing insulation has thus to take care to extend it far enough for adequate cover but not so far as to block ventilation. Also, it has been shown in Swedish laboratory tests of insulating constructions, how quite small gaps in the insulation have a disproportionate effect on heat loss. (K Bankvall, 1977, from Statens Provningsanstalt)

5. Roofspace condensation can be greatly increased by moist air rising from within the dwelling through small holes, particularly around pipes, flues and cables (BRE PD 32/80). It has not been common practice to seal up such holes in the past, but it is necessary now. Failure to do so can lead to considerable losses of energy, as 'stack effect' within the house and roofspace suction frequently combine to enforce substantial heat losses. In the view of the Building Research Establishment (PD 32/80) such leakages can amount to a large proportion (up to 30%) of the total heat loss through ventilation from the house. In blocking holes, care must be taken to avoid using materials that may cause chemical damage to pipes and cables.

Airtightness of wall construction

6. The larger part of heat loss through ventilation in dwellings with solid floor construction seems to take place through gaps around windows and doors, between their frames and the walls, and through unintentional gaps between components - especially at the joints between bricks and blocks, which seem to leak both air and water no matter how carefully built. At one BIH project a particularly exposed (wind facing) wall showed dramatic heat leakage on infra-red thermographs. Removing the lining revealed numerous leakages through block joints, through which cold air could pass from the cavity to the interior, under a shrunk skirting. By inference the same problem should occur within upper floors, where the external wall is unplastered.

7. At another project, it was noted during construction that compressible seals, intended to close the gaps between window frames and the blockwork of the inner leaf, were not effective because the blockwork courses had not been built at the heights anticipated when working drawings were prepared. In the same houses, craftsmen frequently neglected to fill vertical joints between blocks and bricks. The latter were put right when the brickwork was subsequently pointed, but the former (in the inner skin) presumably remained open. After these houses were handed over, air pressure tests found them to be remarkably airtight. However, tests on the same houses a year later found that leakage had doubled - much of the new leakage coming from under the skirtings, which had shrunk to leave a small gap (about 2mm) at floor level - enough for a significant leakage. By extrapolation - BRE's studies of water penetration through brickwork bear out these findings. Thus it suggests that there will be large leakages irrespective of craftsmanship, unless the inner lining (plaster and carpentry) is virtually airtight,

permanently.

8. At another project, a major source of air leakage was an electrical power point built into the single leaf wall between the living room and a meter cupboard with an unsealed door to the outside. Leakage also occurred here at the windows, where well sealed sashes failed to close effectively against the frames which were bent by badly fitted catches.

9. External doors also can be a source of leakage, where slight warping occurs through the seasons, to an extent that some draught-seals cannot accommodate. Here the selection of appropriate seals is crucial: they should be thick enough, soft and genuinely long-lasting.

10. In houses insulated to these levels, heat loss through natural ventilation can account for some 40% of the total heat loss, at one air change per hour. Small leakages could increase this rate to 1.5 or 2 air changes per hour, thereby increasing the total heat loss by 20 or 40%.

11. In cavity construction, the inner leaf of the wall theoretically provides a large part of its resistance to conductive heat loss. In construction, gaps should be avoided as they would admit cold air and thus offset the performance of the wall. The building of joists into an external wall is likely to lead to quite large leakages once the joists have shrunk.

12. While it is desirable to reduce uncontrolled air leakage to a minimum, there must be adequate controllable ventilation to keep the air fresh and control humidity. Experience suggests that where windows are the only means of control, there is an invidious choice between too much ventilation (and the risk of burglary) and too little. Closable ventilators offering 10-20 sq.cms. of free area when fully open are needed in all rooms. These are secure and admit a steady 'trickle' of ventilation all day, to disperse moisture stored in the wall finishes during the periods of high interior humidity. (An increasing number of manufactured windows incorporate such ventilators).

'Internal' wall insulation

13. Two of the BIH projects have wall insulation provided by 'insulating dry linings'. For fire safety reasons these incorporate timber battens over which the plastic foam insulant had to be cut to fit. Site observations showed this was sometimes done very roughly, with more of the insulant being removed than was necessary. Such treatment would inevitably make some difference to the overall performance of the wall. There is some fear, too, that this form of construction may lead to interstitial condensation either within the plastic insulant or on the wall behind. Theoretical calculations are of little value in estimating in advance whether this will occur, because the temperatures of the materials concerned will vary according to the irregularities of construction described, moisture conditions vary a great deal through time and according to the uses of the dwelling and in most cases be subject to air movement within the wall, whether inward or outward. Interstitial condensation is most likely to take place on the down-wind side of the building, or wherever warm air is leaking out. Air

coming in can not cause condensation because it starts relatively dry and its temperature is rising as it passes through the construction. Reports of interstitial condensation behind internally applied wall insulation are very few. This may be because it takes many years before it manifests itself. Alternatively it may be because condensation tends to occur in the coldest weather when winds are in the North and East, and to dry out subsequently when they are in the (more frequent and stronger) West and South-west (see Met. Office wind-roses). A better understanding of the behaviour of this form of construction is especially important in relation to the improvement of existing buildings with solid brick walls.

Cold bridges around windows etc.

14. Two or three houses at the Abertridwr project have suffered condensation and mould growth at window reveals. Only houses with very low energy consumption suffered but both test and control houses were affected. In this detail their construction was the same - the insulating lining to the test houses not having been returned into the reveals. At design stage, the detail was thought to have been adequately protected by a PVC box section cavity closer. It is possible that this detail may have worked but for air leakages into the cavity, subsequently known, and partly attributable to the high exposure of the site. As is often the case, detail design, microclimate and household management regime are jointly responsible.

Wall cavity bridging

15. In cavity wall construction, a common fault is the bridging of the cavity by droppings of mortar on wall ties. If the proper precautions are taken during building this should not happen, but in practice it is quite common. As often as not it does not matter, and water still does not cross the cavity, or, if it does, it does not show through emulsion paint finish. Subsequent insulation by cavity filling can cause such bridges to concentrate a flow of water sufficient to show as a damp patch on the inside. This is a fairly common phenomenon where UF foam is used: fortunately it is quite easily put right by removing bricks, cleaning out the offending mortar, and replacing them. This occurred at one BIH project where mineral wool filling was used - presumably before filling the damp transmitted across bridges was dispersed by ventilation within the cavity. At another BIH site there were many mortar bridges in the control houses, which had normal plaster wall linings. The more highly insulated test houses had insulating wall linings through which the bridges did not show to the inside. They were, however, very obvious to an infra-red survey, emphasising the fact that cavity bridges, besides admitting damp, also transmit heat and increase the wall's overall conductive heat loss.

Wall perimeter insulation

16. A vertical strip of insulation was designed into the floor slab perimeter at one project. This was cast-in with the foundation slab, by being placed against the formwork. The contractors were unfamiliar with the material in this use, and initially had difficulty in preventing the insulation from floating up in the concrete as it was poured. This problem was overcome after the first slab. Subsequently some of the slabs

were used for the storage of materials - unavoidable on this site - and the perimeter insulation became severely damaged.

Built-in Cavity insulation

17. The application of 2 forms of built-in cavity insulation were studied (by the National Building Agency) in the context of policy development. With one of these - foam polystyrene slabs - methods of fixing had been developed by the manufacturer, and instructions given to the contractor. The technique depended on these slabs being fixed back to the inner leaf of the wall, which was built up above the outer leaf to the height of the slabs of insulation which were then lodged between rows of wall ties, flat against the inner leaf. In practice the builders did not manage to clean off mortar from the cavity face of the inner leaf wall before it had set, so the slabs were not positioned correctly. Also, the height of blockwork courses needed to match accurately the height of the slabs of insulation. Neither of these conditions was fulfilled, presumably because other factors governed the block-layers' procedure. Difficulty was experienced in cutting the polystyrene slabs with the few tools normally carried by block-layers and in windy conditions the light, rather fragile slabs tended to be damaged in handling on the scaffolding.

18. Insulation by 'batts' (semi-rigid slabs) of mineral or glass fibre presented few difficulties. However, these are quite difficult to cut in such a way as not to disturb the grain of the fibres, and thus endanger the resistance of the batts to moisture crossing the cavity. In both these instances the problems found could probably be overcome as operatives become more familiar with the materials, acquire extra tools and modify their customary procedures. The 'buildability' of insulated walls has been further studied by BRE and will be published separately.

19. Errors of communication are quite common on a busy building site: usually these are quite easy to put right, but with new materials later modifications may prove difficult. Designers do not usually anticipate such problems. An example is that of a concrete block wall lined with insulation, which makes it a great deal more difficult to modify when a detail (such as a balanced flue duct) has been forgotten.

20. Projects using new materials and techniques for the first time are particularly vulnerable to a host of problems arising out of unfamiliarity. Special attention, thought and supervision are essential if failures are to be avoided. Some of these may prejudice the weathertightness of the building or ultimately its life. Others will be invisible and possibly not detected except by air pressure tests or infra-red thermography, but will have an influence on the thermal performance of the finished building. The continued study of failures in cavity filled walls seems to show that a certain number will occur no matter how hard the builders try. Modified constructions could well cost more than putting right the (relatively few) buildings with faults that show.

Vulnerability to frost

21. The severe winter of 1978/79 produced many instances of brick and rendered walls failing due to frost attack to the surface. Some of these would have been insulated walls but in no known case was it possible to prove that frost damage would not have occurred had the wall not been insulated. Nevertheless it is quite certain that a wall which is insulated is necessarily colder on the outside, will dry out more slowly after rain, and is thus a little more vulnerable to frost damage. It is advisable therefore to choose, for well insulated buildings, bricks which are sufficiently frost resistant for the rather worse conditions they will experience.

Conclusions

22. This chapter has raised two important issues: on the need for the design of buildings to treat overall insulation as a fundamental structural element, and to ensure their assembly using new or modified techniques which introduces the minimum of technical risk.

23. Insulation must be considered at the start of the design process, especially in larger domestic buildings (e.g. flats) with a distinct structure. Any cold bridge should be regarded as a design failure. Insulation standards can be expected to increase, so that design approaches should be forward-looking. The detailing of lintols, jambs and cills, foundations and party walls should aim for consistency of thermal resistance.

24. As to building techniques and technical risks, the potential problems have already been discussed widely and will no doubt continue to be - they involve all sectors of the construction industry.

> Manufacturers should continue to study building practice in the context of 'normal' site priorities, and amend their advice to designers and builders accordingly. New components should continue to be developed and tested to solve outstanding problems.
>
> Both manufacturers and designers should revisit sites where new methods have been used, to observe the effect of time.
>
> Designers should discuss details and site experience as widely as possible, to ensure the dissemination of good practice.
>
> Authorities and other builders should do their utmost to build to higher standards than are mandatory (preferably achieving a U-value of 0.6 or lower in walls), and welcome (legitimate) visitors to their sites to observe procedures.

Insurance and site testing

25. In general, the risk of technical failures should be recognised, and appropriate insurances arranged for at the contract stage. Methods of testing both airtightness and the integrity of insulation already exist, but so far are used mainly by researchers. In Sweden, air pressure testing is mandatory for a significant proportion of all new houses. This excellent

practice has had a very worthwhile effect on contractors and their craftsmen - who now compete with each other to achieve the best results. It is nonsense to argue that Swedish craftsmen are inherently better than English - they display all the same bad habits. But they do respond to a challenge involving an objective test. This is a practice we would do well to adopt.

3.2. HEATING SYSTEMS

Range of systems in the Programme

1. In the 'existing' projects, heating systems were the same in both test and control houses, and not altered in any way in connection with the BIH experiment. In the new-build projects they were all modified to some degree, the Washington and Abertridwr projects being the most sophisticated. The latter is to have boiler output and input monitored, continually at very short intervals, to determine efficiency. The systems were:

Whitburn	-	electric underfloor or storage heaters plus electric radiant fires
Hamilton	-	gas fired radiator systems plus gas radiant fires
Plymouth	-	gas fired warm air (partial) heating plus some radiant fires (in addition or as an alternative)
Brampton	-	electric storage radiators and some oil fired systems (project ignored for lack of data)
Coventry	-	gas fired radiator whole-house systems throughout, plus gas radiant fires. TRV's in test houses, and test house boilers down rated from 40,000 to 30,000 BThU's. 1 TRV in living room only of control houses
Darlington	-	electric ceiling heating plus electric radiant fires
Washington	-	electric panel room heaters (individually and centrally controlled) plus thermostatically controlled electric radiant living-room fires (added later)
Abertridwr	-	gas fired radiator systems, whole-house in control houses and partial in test houses, all fitted with TRV's and over-riding thermostats in living-rooms. Control houses 14.7 KW and test houses 8.2 KW boilers.
Bo'ness	-	electric storage heaters with powered warm air distribution, test houses storage blocks smaller.

Temperatures and users' requirements generally

2. The lessons of individual projects in terms of systems and their use and controllability are discussed in Section 4 and Appendix A. Table 1.1 summarises recorded whole-house temperatures. These reveal to some extent the comfort expectations of the various tenants, some cultural effects (e.g. the very warm houses of some of the Welsh mining community at Abertridwr - a phenomenon that was not evident at Washington) and in particular the tendency for electrically heated houses to be kept at lower air temperatures. It is tempting to assume that where heating was wholly by electricity, households reacted to

its high cost by adopting lower standards. But this is not necessarily the case. With the exception of the Bo'ness project, all those heated by electricity had radiant living-room fires, which may well have provided comfort equivalent to any other form of heat, while they were in use. Some houses inevitably had (on average) lower whole-house temperatures because the heat was not so well distributed elsewhere, and even in the room where it was used, would often be switched off before the room air was warm.

Range of comfort standards chosen

3. A comparison of houses with identical heating systems showed considerable differences of 'comfortably heated space'. Presumably people's choice reflected their means and priorities, within the scope offered by their house and system together with any chosen modifications to it. Such priorities will decide the acceptable heating arrangements for future better insulated houses and presumably for more expensive fuels. There is evidence (e.g. from Bo'ness, Hamilton and a few houses at Abertridwr) that people will 'under-use' heating arrangements in order to bring running costs within their means. If they cannot either reduce heating periods nor shrink the heated area sufficiently to achieve this they will import other appliances - such as portable gas or paraffin heaters to allow them to do so with a consequential effect on the fabric of the house (e.g. condensation and mould). It might be added that not all people use rooms or even houses as conventionally assumed (Appendix A).

The smaller heating system

4. There is plenty of evidence of the differences in thermal behaviour between highly insulated houses and conventionally insulated ones.

5. At Coventry, with radiators in all rooms of both test and control houses, but with thermostatic valves throughout test houses, the recordings showed quite frequently that the bedroom temperatures of test houses rose above the valve settings, when downstair rooms were reaching their peaks of temperature.

Can upstairs radiators be omitted in a well-designed, well insulated house?

6. The implication of this observation at Coventry is that the upstairs radiators were redundant - the living room heated to 18-21degC warmed bedrooms to 17-18degC. Upstairs radiators can be said to still be needed to bring bedrooms to desired temperatures. In the example quoted sufficient heat was rising through the house to exceed the temperature the household wanted in bedrooms (as demonstrated by their choice of TRV setting). This evidence showed how much heat is transferred upwards by natural convection.

7. At the Abertridwr project, the test houses had little more than a partial heating system - there was originally one radiator on the landing but none in bedrooms other than a hot distributor pipe under the floor. All radiators have TRV's. The control houses have whole-house heating as well as a larger boiler. Early monitoring demonstrated that the test house systems were adequate even in cold weather. However, in due course some

tenants complained that their main bedrooms were cold. These rooms have dual aspects, hence an unusually high heat loss and air leakage for houses of this type. Their underfloor hot pipes were also missed out - the installer did not appreciate their importance to the design and mis-routed them. The landing radiators were subsequently moved into the main bedrooms in the hope of improving heat distribution without increasing the total heat input. This appears to have been successful. At the time of complaints the temperatures described as 'cold' were 14degC before the morning switch-on of heating (these households were conditioned to high standards of comfort. While the Coventry evidence could not be conclusive in itself about the adequacy of partial heating in well insulated houses, the Abertridwr evidence seems to be so. However, the latter, being insulated internally, have relatively low thermal capacity and hence a fast cooling rate in bedrooms, which would leave them comparatively cold first thing in the morning - a critical comfort factor. There may be a case for continuing the well-tried solution of electric fires in bedrooms, coupled with a well-conceived distribution of heat from downstairs for background warmth and to prevent condensation (see also Appendix A).

Search for an appropriate standard

8. A house with upstairs radiators does have advantages. It allows, by simple manipulation of valves, bedrooms to be heated irrespective of whether downstairs rooms are (manual or thermostatic). This facility is probably not often required and is expensive to provide - to some it may appear a luxury. The question at present is whether households would feel adequately served by houses with partial (ground floor only) central heating and higher levels of insulation, give more comfort than less well-insulated and partially heated houses at lower capital and running costs than those with whole-house heating. If this is acceptable the acknowledged demand for whole-house heating might thus be met by extra insulation, and the additional cost of heat distribution to bedrooms saved. However, as well as providing an acceptable standard for the better off, houses must accommodate the needs of those who are forced into strict economy.

9. The accumulated evidence of all projects showed that it may be more difficult to limit both heating periods and heated areas in well insulated houses, unless understanding of both thermal capacity and convective air movement are brought to bear on the design, and even then the opening or closing of doors may present a problem. It will be very important to test out in occupied houses methods by which tenants control the temperatures of individual rooms, to see how much trouble those with least means will go to, to make such economies as are possible. The Washington project, with individually controllable heat sources in all rooms, and the most expensive fuel of all, is expected to provide valuable evidence, when detailed results are assessed.

10. To sum up, technical and economic factors suggest certain directions:

smaller and cheaper heating systems, at a capital saving that can be traded off against more insulation

fewer heat emitters, in the belief that natural air movement will serve to distribute heat around the house, unless positively prevented.

11. An important caveat is that through-circulation of heat is essential, to avoid cold pockets of stagnant air. Vapour can travel horizontally through still air, whereas heat can not. Stagnant pockets at cold surfaces invite condensation and mould especially in cupboards or behind furniture. But it remains to be demonstrated whether the above directions will lead to designs that will work for the full range of households of all different sizes and lifestyles. To ascertain this both more exploration of data and more practical projects are needed.

Apart from the foregoing key considerations of heating systems in well insulated houses there are others which must not be forgotten.

Single heat source: hot water supply

12. Consideration of hot water supply has arisen not from direct experience of BIH projects but from theoretical considerations undertaken in association with them. For example, for the test houses at the Abertridwr project, the smallest available boiler was used, having an output of 8.2 kW, to meet the demands of a house whose maximum (design) heat requirement is about 4 kW including that available from incidental gains, and an intermittent demand for water heating normally estimated at 3 kW. Hence the hot water allowance is 35% of the total output, and heating is expected to require no more than 47%. There is therefore quite a generous reserve for intermittent heating (faster warm-up) - via radiators capable of greater than the total heat loss, in order to heat the house quickly. During the summer all this power is available for hot water only and will waste a lot of gas whenever it is 'cycling' without hot water being drawn. Controls that will shut down a boiler at such times are now being introduced, as British Gas policy. Another alternative arrangement would be to have two boilers, one each for heating and hot water. Here the extra capital cost would probably exceed the economy in fuel and flue-heat losses may increase. Another approach patented some time ago but only now on trial, is to provide a large well insulated storage tank as a reservoir of heat for both purposes. This is 'topped up' with heat at relatively infrequent intervals from a single small boiler working at a peak of efficiency for quite long bursts and shut down between times (in fact the size of the boiler would matter little). A possible disadvantage is the heat inevitably lost from the tank - this however contributes an additional incidental heat gain sufficient perhaps to mitigate the worst consequences of intermittent demand on the space heating system. This example demonstrates how heating methods at present in use seem to be dominated by conventions of practice and existing hardware which may well be inappropriate to a future of scarce energy.

Washington - lessons re system output in heavy structure

13. The Washington project demonstrated some important lessons about house thermal capacity in relation to intermittent heating. The houses were designed with a 'heavy' structure, quite rightly, as a defence against the possibility that solar heat gain would make them intolerable in the summer. However, due to the unexpected rise in the cost of electricity between design and occupation, they were, when occupied, heated far more intermittently than expected. The intention was that the individual room heat emitters would be used together as a 'whole-house' system, ensuring a warm structure in the winter giving whole-house comfort with strict temperature control. In the event, with greatly increased electricity costs, many tenants tried to heat living rooms only, and those intermittently, but the living room heaters proved inadequate for the demand and had to be replaced by larger ones incorporating a radiant element. Most of the house structures never became really warm, thus being more susceptible to condensation.

14. The daily temperature profiles recorded at each project show how the majority of households operated a regular intermittent heating regime. Full 'comfort temperatures' (20degC and above) tend to be reached only in the evening. It is difficult to envisage less intermittent heating if fuel prices are to increase in real terms. Therefore the house and its heating systems should be designed to be capable of operation to provide the levels of heating required at the times required. Heating provided at other times (than when required) should not increase the running cost over that of the intermittent regime. In either case, the design of the structure and the heating system should be such as to avoid condensation.

'High-low' system performance

15. The lesson distilled from this experience was that a heating system should be able to perform economically in a 'high-low' manner. That is to say it should ensure that the structure stayed warm enough at all times to prevent condensation, and also to keep reasonably small the extra requirement to be met intermittently as needed by the household for full comfort conditions. The 'reservoir tank' described above should serve this purpose.

16. A further lesson from Washington was that, especially in the context of rooms in a cold structure, radiant heat was thought by residents to be essential - they demanded (and got) electric fires. The same appeared to be the opinion of many at Bo'ness, who obtained paraffin stoves for their living rooms to supplement the electric warm air heating systems. These are of course a little cheaper to run, but the fact that some of these fires were elaborately installed on a traditional 'hearth' seems to have something to say to the designers!

3.3. VENTILATION

1. Throughout the calculations, assumptions had to be made about average ventilation rates during the heating season in the (occupied) dwellings. These have been based on conventions, defined by PSA engineers, as follows:

Living rooms	1.5 a.c/h. (air changes per hour)
Kitchens, bathrooms	2 a.c/h.
Circulation	1 a.c/h.
Bedrooms	.75 a.c/h.

2. Tests of both air infiltration rates and air leakage under slight pressure were carried out at Brampton, Plymouth, Coventry, Washington and Abertridwr. (Work carried out by BRE, University of Bristol, University of Newcastle and British Gas). These tests taught something about the behaviour of the houses, but not about the long-term ventilation rates of the dwellings, when occupied, in different seasons and wind conditions. The techniques used were too crude to take account of occupancy and for these purposes, only recently, have suitable techniques been developed for the BIH programme.

Calculation of ventilation rate by subtraction

3. In the absence of reliable measured data it has been necessary to use conventional assumptions. There is a crude means of estimating ventilation rates by subtraction of fabric heat losses. Most commonly more heat seems to have been lost than gained, suggesting that either estimates of gains had been too high or losses too low. Possible reasons are:

(a) Ventilation greater than conventional assumptions (likely)

(b) Fabric heat losses greater than calculated (possible, but should be small)

(c) Metered energy inputs over-estimated (possible but unlikely)

(d) Gas boiler efficiency over-estimated (likelihood differs with site)

(e) Temperature monitoring consistently read low (not very likely).

4. It seemed that the conventional assumptions about average ventilation rates were generally a little on the low side. The analyses of Darlington includes a graph (Figure 3.1) which suggests ventilation rates dropped to about 0.5 a.c.h in the coldest weather, but increased to about 1 a.c.h. in mild conditions. While this analysis is by the crude subtraction method, the above suggesion seems plausible, for want of a better one.

Mild weather ventilation rates

5. There is a body of opinion, based on some research, that households increase their ventilation rates in milder weather (there seems to be little evidence of this outside the UK). In due course it may be possible to study other BIH projects to see whether this Darlington evidence is supported.

6. In better insulated houses, heat losses through ventilation are of increased significance. For example, in an end-of-terrace, single glazed test house on the Coventry site, at 1 air change per hour the ventilation losses are more than half the fabric losses - at 2 air changes they exceed fabric losses (Figure 3.2). A halving of the ventilation rate through a heating season from an average of 2 a.c.h. down to an average of 1 a.c.h. should consequently result in a reduction of 25% in the 'total heat required' to heat the house. Given 50% incidental gains, this would yield a 50% reduction in space heating fuel over a season, all other things being equal. However, this contention holds good only if it is acceptable to reduce ventilation rates to this degree, and if it is practically possible.

Swedish practice

7. In Sweden, an air change rate of 0.5 a.c.h. is now mandatory for new housing. This has to be provided by a power ventilation system which is adjusted to the correct delivery before the house is occupied. This regulation is based on the field measurements which show that such a rate is acceptable to households and will insure against dangerous pollutants, notably the radioactive gas radon and the irritant gas formaldehyde, either of which can come from certain common building materials. Ventilation rates above this level would be needlessly wasteful of energy. The power ventilation systems apply a constant negative pressure (suction) to the houses, so that any leakage in their extremely tight envelope will be inward rather than outward, hence avoiding interstitial condensation (cold, dry air meeting warmer surfaces can not condense). Tightness of construction, (normally timber frame) is assessed by a standard test for leakage under both positive and negative pressure. Heat recovery from ventilation is not seen as cost-effective in Sweden, even though winters are significantly colder than Britain, so the benefits would be greater.

8. For the UK there are the following objections to mechanical ventilation:

Running cost (400 kWh, or £16, per 30-week season at 80 watts)

Noise and vibration of fans (those installed at Washington and Coventry were switched off by tenants, either for these or cost reasons)

Leakiness of normal houses: we can not yet build airtight enough to justify mechanical systems

First cost and maintenance cost

'Extra over' ventilation through voluntary opening of windows may well over-ride the intended controlled rate for much of the time.

9. The mechanical systems fitted to the Coventry houses were very cheap and simple, and relied on pressure supplied from a fan in the roof feeding air via the landing and out through other rooms. Each room was built with a non-closable ventilator with a free area of around 25 sq.cms (4 sq.ins). The net result (see Figure 3.3) has been that in windy weather air blows straight through the houses. Air pressurisation and infiltration tests were done, in an attempt to model, theoretically, the performance of these houses across a range of windspeeds. It was not possible to test all relevent combinations of fan status so the houses were measured in the state in which it was expected they would be used. Hence the leakages from the house envelopes over and above those through the ventilators is not known, nor whether the houses were relatively leaky or not. Heat balance calculations, however suggest the ventilation rates are not abnormally high.

Air leakage in typical UK houses

10. A consensus of research into air leakage of typical new UK houses suggests gaps around windows and doors account for not more than one-third of the total with all windows and doors shut. Intensive studies at the Abertridwr site have contributed to the belief that gaps into the roofspace are likely to account for the largest single share, to which a loft hatch usually contributes a lot, but so do gaps around pipes, ceiling light drops, and quite narrow cracks in ceiling finishes. It has to be appreciated that any air passage through ceilings are usually subject to both pressure from below (stack effect) and suction from above (due to wind across the roof) and hence lose warm air more consistently than most other leaks. At the same time they generally escape the notice of the householder since their leakage is of warm air going out, and there is no tell-tale cold draught. (BRE P.D. 32/80).

11. Walls, too, seem to be subject to leakage, though rates vary with the type of construction. Most wall cavities are ventilated to the outside air through weep-holes. Also it seems logical to assume there is likely to be some general leakage through an apparently sound wall (BRE Driving Rain Studies). In either case, air will then leak into or out of the house wherever the inner skin is not effectively sealed. In 'wet' plastered walls such leakages will normally be limited to zones between ceilings and floors, and any unplastered wall behind skirtings. The former are greatly exacerbated by built-in joists, and the latter by the subsequent shrinkage of the skirtings and/or joists. In the Abertridwr project some of the air leakage rates (under a pressure test) doubled after a year of occupation. Skirting shrinkage was thought to be responsible, together with the seasonal warping of external doors. Most leaks can give rise to either incoming or outgoing draughts, depending on wind and temperature. Incoming draughts are dry, and in time can cause shrinkage. Outgoing draughts can cause interstitial condensation. Changes of wind will of course often reverse draught direction and hence mitigate these effects.

12. Also at Abertridwr, when some panels of the insulating dry lining were removed air leaks would be felt through many of the joints in the inner skin blockwork. The blocks themselves may well have been porous to air, too. As with brickwork, such leakages are of little significance so long as the passage of air is barred somewhere, and continues to be barred for the lifetime of the house. If air does penetrate, however, its cold flow will effectively increase the thermal transmittance of the wall a little. At the Washington project air leaked through the back of a power point chased into a wall - a fault found elsewhere.

13. Tests by BRE have shown that timber frame constructions also tend to be susceptible to leaks. Joints between components are quite easily taken care of, though need to be tolerant of:

later shrinkage
rough handling
unevenness of masonry and concrete work.

Effect of opening windows

14. There is evidence from the Programme (and from BRE) that opening windows has a greater effect on ventilation rates than is usually realised. For example, opening a living-room window at Plymouth, by the smallest possible amount, increased the room air change rate fourfold. Comparable effects have also been measured at Abertridwr. For as long as occupant control of ventilation is the normal means in UK houses, some far less crude method of regulation is needed.

Need for finer control of natural ventilation
Safety considerations

15. While buildings remain far from airtight, therefore susceptible to outside wind pressures, even the smallest controllable ventilators need to be closable progressively down to zero to allow for occasions when structural leakages alone are adequate. These are usually known as trickle ventilators. Trickle ventilators will not suffice for combustion appliances - even small ones. There are of course considerations of safety to do with the air needed for some combustion appliances (including cookers) but clearly the time has come for all such requirements to be met by means that do not prejudice the energy economy of the house as a whole i.e. direct to the appliance rather than through the room. Evidence from the Washington project suggests that 'trickle' ventilators tend to reduce the opening of windows. They are being further tested in several houses at Abertridwr, under the Department of Energy's Demonstration Programme.

Ventilation and heat distribution

16. By the same process as heat is lost from a house by air leakage, so heat is moved around inside the house primarily by convection taking heat away from some rooms and warming others. This lateral movement of heat is caused by wind direction and/or general convection currents coupled with fabric heat losses. A study by British Gas of the Abertridwr houses shows a predominant ventilation path from the front door to the bathroom window - taking heat needed by bedrooms. Further study of this phenomenon may lead to design criteria for ventilation hardware

and/or house siting and orientation. It will be a critical design factor wherever the number of heat sources is reduced, to match higher levels of insulation.

Lateral drift of heat

17. For a room 4m x 6m x 2.5m high, at a 20degC temperature difference from that outside, leaking at a rate of 1.5 a.c.h., the heat lost would be of the order 600 Watts (which would of course have to be replaced in that room to maintain its temperature). If this room was on the windward side of the house, leakage in windy weather would cause heat to drift laterally to other rooms which would of course benefit them. If the room were on the downward side all this heat would go straight outside These phenomena are normally taken into account in heat loss calculations for the whole house, but their effect within the house is to make it difficult to maintain predetermined temperatures in individual rooms. This problem is even more acute insofar as natural air movement is relied on to distribute heat. Hence, while the ideal form of heat source for a very well insulated house may be a single central appliance distributing heat by natural convection, such an arrangement would fail if there were excessive lateral drift of warm air. A natural ventilation system, therefore, should (ideally) aim to provide fresh air from a central source rather than through outside walls. Preferably it should be powered by stack effect, as this means is cheap, silent, virtually maintenance free and unaffected by wind direction. But there are other problems to be solved on the road to that solution - effective sealing, circulation of fresh air, and an extract cowl that is genuinely unaffected by wind direction.

Effect of high ventilation rates on boiler efficiency

18. Yet another problem associated with well insulated houses having conventional response to outside wind is in relation to boiler size. From Figure 3.2 it can be seen that the ratio between the boiler sizes needed for conditions of 0.5 and 2 air changes per hour could be as great as 2:5. Such a wide variation normally leads to boiler oversizing and a consequent loss of efficiency in mild and relatively calm conditions. In practice such a large variation in ventilation rate is not normally included in boiler sizing calculations, but neither is there usually a realistic estimate made of incidental heat gain. Hence good control of ventilation rates affects energy economy, but it is essential that the control works in practice and maintains its performance over the years.

19. In conclusion, uncontrollable ventilation rates in well insulated houses tend to:

lead to excessive energy use
make it difficult to distribute heat economically
make boiler oversizing a necessary precaution, with a consequent loss of efficiency.

Condensation and mould growth

20. To date, condensation sufficient to cause surface mould growth in the house has only affected one BIH site, that at Abertridwr (See Section 3.1). Here mould has grown on the bedroom window reveals of a few houses - both test and control. The test houses have mostly unheated bedrooms but the control houses have radiators in all of them. The site has tenants of very low income, and in fact two of the houses afflicted are those with the lowest gas consumptions on the site. The window reveals are potential cold bridges in all these houses but have only generated mould in a small number where the ventilation/heating/house use regimes have produced critical conditions. Thought is being given as to whether suitable advice can be offered to these tenants so as to eradicate the problems without an increase in fuel cost. If a cure is possible it will probably involve reducing bedroom ventilation during periods when the houses are unheated, so that the retained heat will keep the structures warmer.

Roofspace condensation

21. Improved structural insulation can generally be expected to the risk of surface condensation in the dwelling. However, it ma slightly increase the risk of condensation in a roofspace - if ste not taken to adequately ventilate the roofspace and to seal off from the ceiling under it - and of interstitial condensation else Condensation as a 'building failure' is discussed in Section 4.

Interstitial condensation in walls

22. Interstitial condensation can affect walls of timber frame construction and also affect those of more conventional construction, but in those cases no damage is likely, other than perhaps some loss of thermal resistance if insulating materials become wet or if structural timber were affected. The Coventry houses are of timber frame construction and for this reason were thoroughly protected by polythene vapour check membranes in all walls of test houses. In fact there was some difficulty in treating certain details such that a true vapour barrier was impossible to achieve. The moisture content of structural timbers was checked at regular intervals by remote reading electric-resistance probes. In the event, although many of the readings were quite high, only the sole plates were at risk having moisture content above the conventionally 'safe' level of 20%, and these were of treated timber. Such results must however be regarded as inconclusive because it is likely that wind penetrated this construction to some extent, perhaps sufficient to safeguard the timber where tighter construction may have been at risk. This must still be regarded as an area of some considerable risk and investigations need to be continued. Currently there is little ground for confidence in an installed vapour barrier in the U.K.

3.4. PROBLEMS - of concern and requiring further investigation

This report has identified 15 subjects for further work, in 7 categories:

1. Design guidance from existing knowledge:

    (a) How to design to avoid Summer overheating from solar gain (relevant also to floor insulation)

    (b) What effect will better wall insulation have on frost damage to wall materials/

2. Design guidance to follow user studies:

    (a) What is the range of the users' requirements for house thermal performance, heating systems and controls, and ventilation methods, relevant to well insulated houses and escalating fuel prices, and the full range of incomes and lifestyles? Note: this must not be expressed in terms of existing hardware, but serve to offer specifications for it.

    (b) Could a heating method, providing a constant low level of heat and 'topping up' on demand, be acceptable to people who heat intermittently?

    (c) Are the latest developments in low-energy domestic lights acceptable to households?

3. Design guidance to follow user studies and practical trials:

    (a) How can heating controls be made more comprehensible?

    (b) How can domestic meters be designed and located so that energy consumption is constantly noticed by householders?

    (c) How can houses be designed and managed to avoid condensation?

4. Practical trials needed:

    (a) In highly insulated houses, will bedrooms become warmer than some households want them? Will low income families complain that they cannot afford warm bedrooms but can not avoid them? Should the staircases be enclosed to control heat transfer?

    (b) What fuel savings can be made by teaching households how to manage their houses and heating arrangements in the most effective way?

    (c) What savings can be made from modifications to rooms and heating systems to provide comfort with the minimum fuel consumption.

5. Practical development followed by design guidance:

(a) Develop and prove in use a natural ventilation system that is cheap, foolproof, practical, proof against burglary, unaffected by wind conditions and controllable by the household (possibly for kitchens and bathrooms only at first).

(b) Develop and prove constructional details to minimise both cold bridging and structural air leakage.

(c) Develop and prove application of heating controls that give accurate control of temperatures, maximise boiler efficiency, do not interact with each other and are suitable for improving existing systems.

6. Practical application development from existing knowledge:

(a) Develop practical on-site tests in new houses, to measure their heat loss and air leakage rates. The same tests should be adaptable for existing houses with the minimum of disruption to occupants (study Swedish practice).

7. Question established beliefs and verify anew:

(a) Are the accepted (in the UK) U-values for floors realistic in the (perhaps majority) context of intermittent heating?

8. A further, separate issue should be explored, that of insulating to higher standards still, in the direction of Danish and Swedish practice. The objective would be a house for which space heating is needed only occasionally, as such houses will 'float', heated by incidental gains only, at outside temperatures in the band 5-9degC, or even lower in terraced houses. The capital cost savings in heating plant would be considerable, but both design approach and living routines would need to adjust to suit. Such houses would show fuel savings more likely to catch the public imagination than those studied in the BIH programme. Key factors in the design would be ventilation and the distribution of heat by natural convection.

A few examples of such houses already exist in the UK, the most significant being a local authority estate of over 60 dwellings imported prefabricated from Sweden. These are 3-bedroom 2-storey terrace houses, and have a rate of heat loss of around 150W/degC with ventilation at 1 a.c.h. - which accounts for half the total. They are all-electric, and space heating is estimated to use no more than 1650kWh annually (very little non-electric heating is used). Consumption data collected over 5 years have been studied. Total annual consumption for all purposes averages 8150 kWh, of which space heating is no more than about 20%.

At this level attention is lead to other areas for study - particularly the consumption of electricity and whether there is room for reduction through appliance and fitment designs.

<u>FIGURE 3.1. - DARLINGTON. VENTILATION RATES REQUIRED TO BALANCE ENERGY IN AND OUT WITH TEMPERATURES IN AND OUT</u>

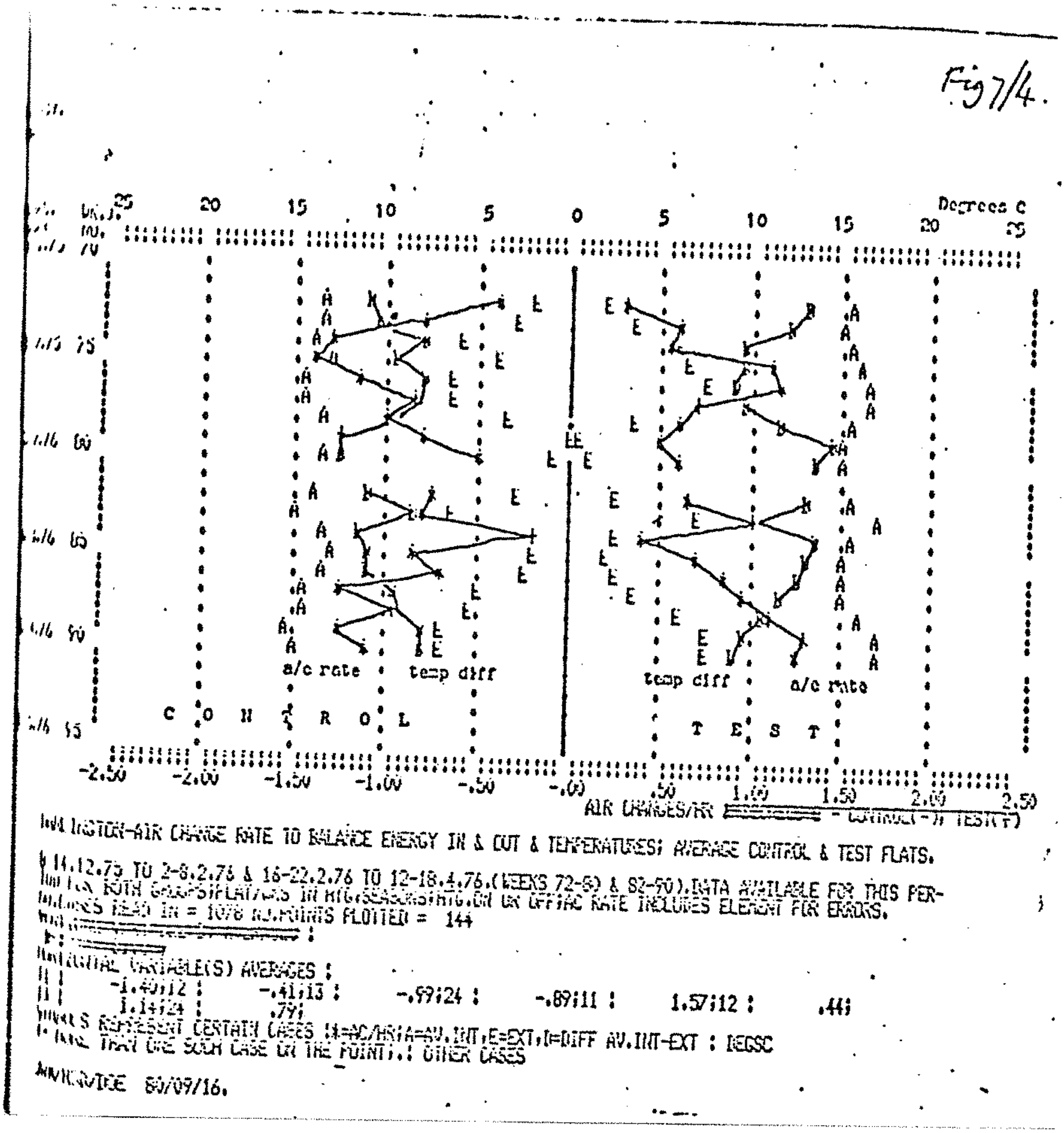


FIGURE 3.2. - VENTILATION RATE COMPARED WITH FABRIC HEAT LOSSES

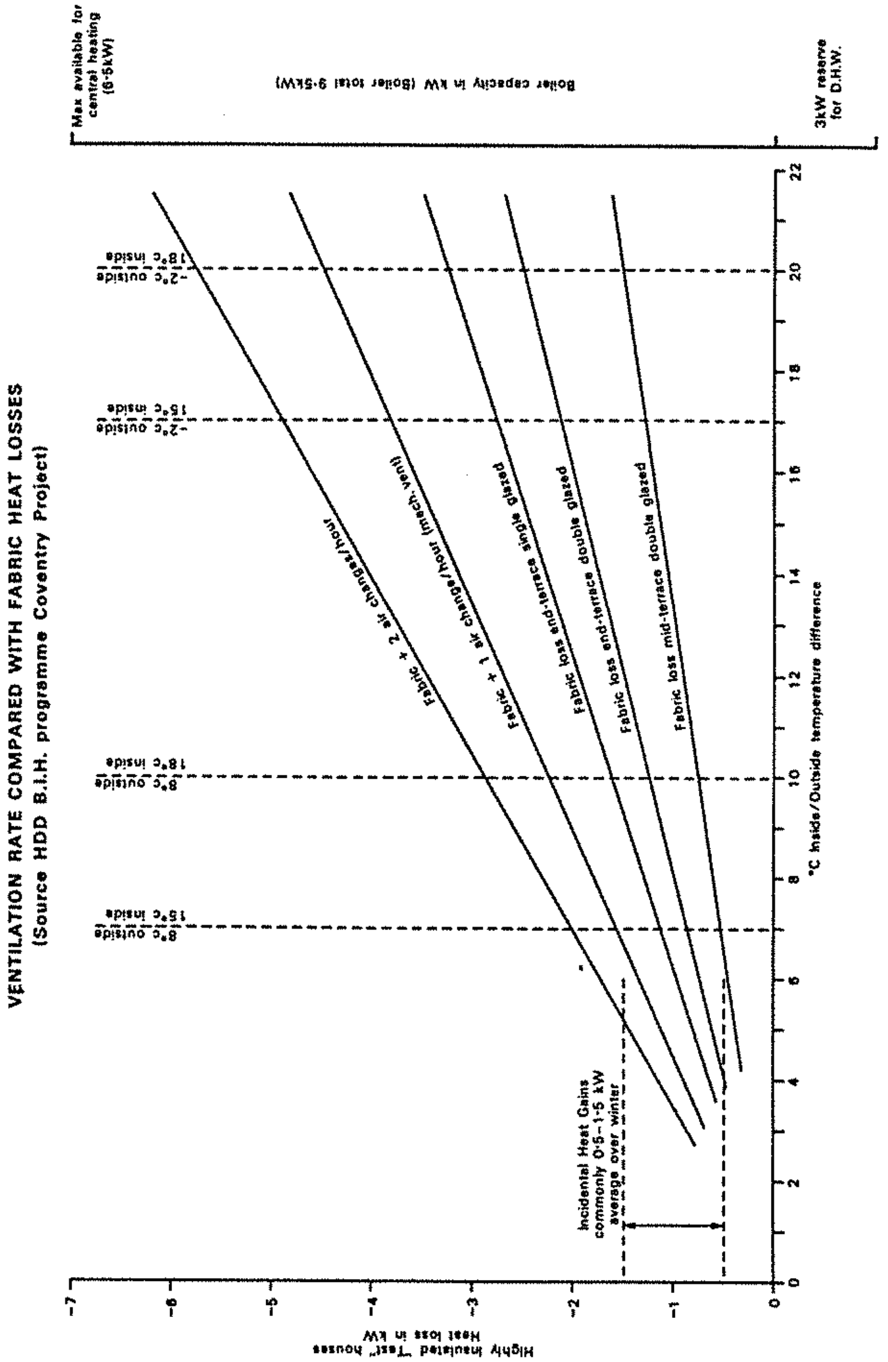
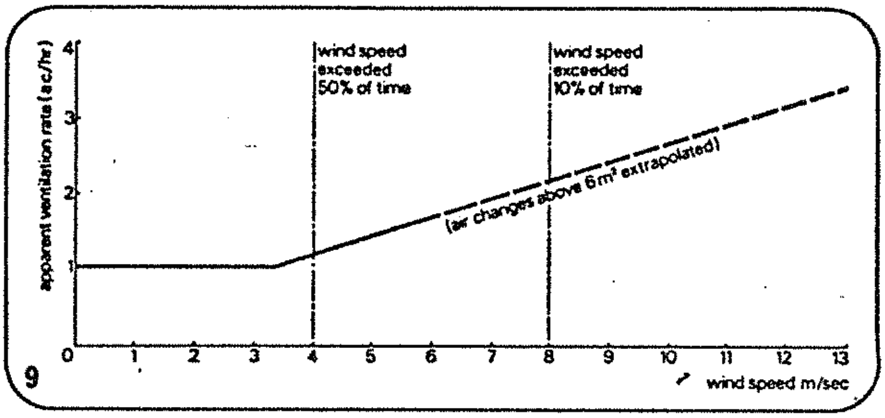


FIGURE 3.3 - VENTILATION RATES - COVENTRY



APPENDICES

APPENDIX A - INDIVIDUAL PROJECT DETAILS

A/1. WHITBURN

1. Whitburn is between Glasgow and Edinburgh, at an altitude of about 200m above sea level.

The project involved some 56 dwellings, a mixture of 2 and 3 bedroom terrace houses, and a few flats, all built in 1961 (Figure A.1.1) for the Scottish Special Housing Association. These have rendered cavity walls and tiled roofs insulated with 25mm of quilt insulation, as well as 12.5mm fibre board sarking. For the experiment, half of the number were cavity filled with UF foam and their roofs additionally insulated with 100mm glass fibre. Pedestrian and vehicular tunnels through terraces were also insulated, reducing calculated heat losses (including ventilation) by about 25% in all. Incomes are about average for public sector tenants. There being no gas on this estate, heating is by electric floor warming or storage heaters, both off-peak, supplemented by electric fires. There is no heating upstairs.

Monitoring

2. Temperatures were monitored with thermohygrographs in batches of 4 hours for 1-week periods, and only a selected 4 houses received continuous monitoring, for a period of 11 weeks. The 1-week tests were repeated later in winter 1974/75 and again in 1975/76. External temperatures were recorded with similar instruments.

3. Internal temperatures thus recorded would give a heating pattern and living room comfort temperature for each house. These would be valid insofar as temperatures were independent of outside conditions. In practice tenants had some control over their living room temperatures but since the main heating was by electric fires, control was limited to one, two or three bars which, especially in the Test houses, was too crude. Background heating by electric under floor or block storage means was thermostatically controllable during the 16-hour 'off-peak' period. Other rooms offered little chance of control, and bedrooms in particular would be strongly influenced by outside temperature, except where supplementary heating was used. Nevertheless, temperatures averaged over all of each group of houses would incorporate examples typical of much of the winter and should thus be fairly representative of that group.

Results

4. The average differences in total consumption between test and control houses was 2310 kWh per dwelling over the period December 1974/December 1975, about 70% of this being realised out of the on-peak supply. Records of temperature show that the test houses were warmer. Figure A.1.3 is reproduced from PD 23/78 (BRE). Living-room temperatures at 9p.m. were virtually the same in both groups (the difference being statistically insignificant). Living-room mean temperatures were different by about 1.3degC, those between 1.5degC, and the differences between groups in whole-house average 1.5degC.

5. It can thus be argued that such differences in temperatures as were observed were largely if not wholly the result of uncontrollable differences in the thermal behaviour of the houses, brought about by the insulation. The consequences of such differences upon savings in fuel consumption are discussed in Section 2.1.

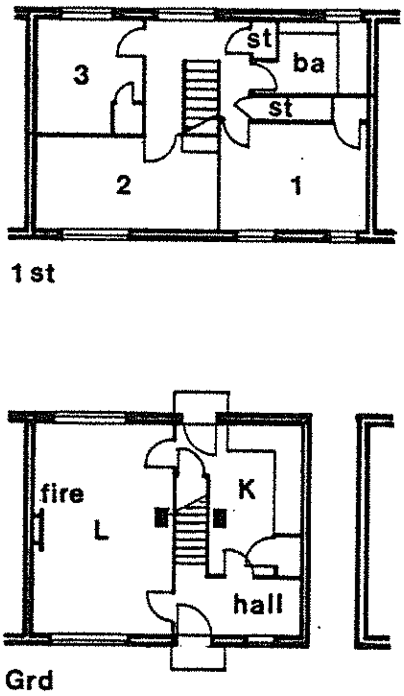
Roof condensation

6. A study of roofspace condensation has been conducted in these same houses, many of which had white mould growth on the fibreboard sarking. At some point since their construction, ventilators had been installed in the bedroom ceilings in an attempt to eliminate condensation in the bedrooms. These were blocked at the start of the project in the insulated houses, and subsequently in the rest. After the installation, conditions in the highly insulated roofs were rather worse than in the control group, with significantly more of the timbers at risk of rot. The deterioration induced by the insulation was similar to that occurring in a very severe winter. Subsequently ventilators, to BS 5250, were installed in the eaves of half the roofs. These greatly reduced the risk of rot, conditions in the roofs becoming better than before they were insulated.

FIGURE A.1.1. - WHITBURN - 5 PERSON TERRACE HOUSE

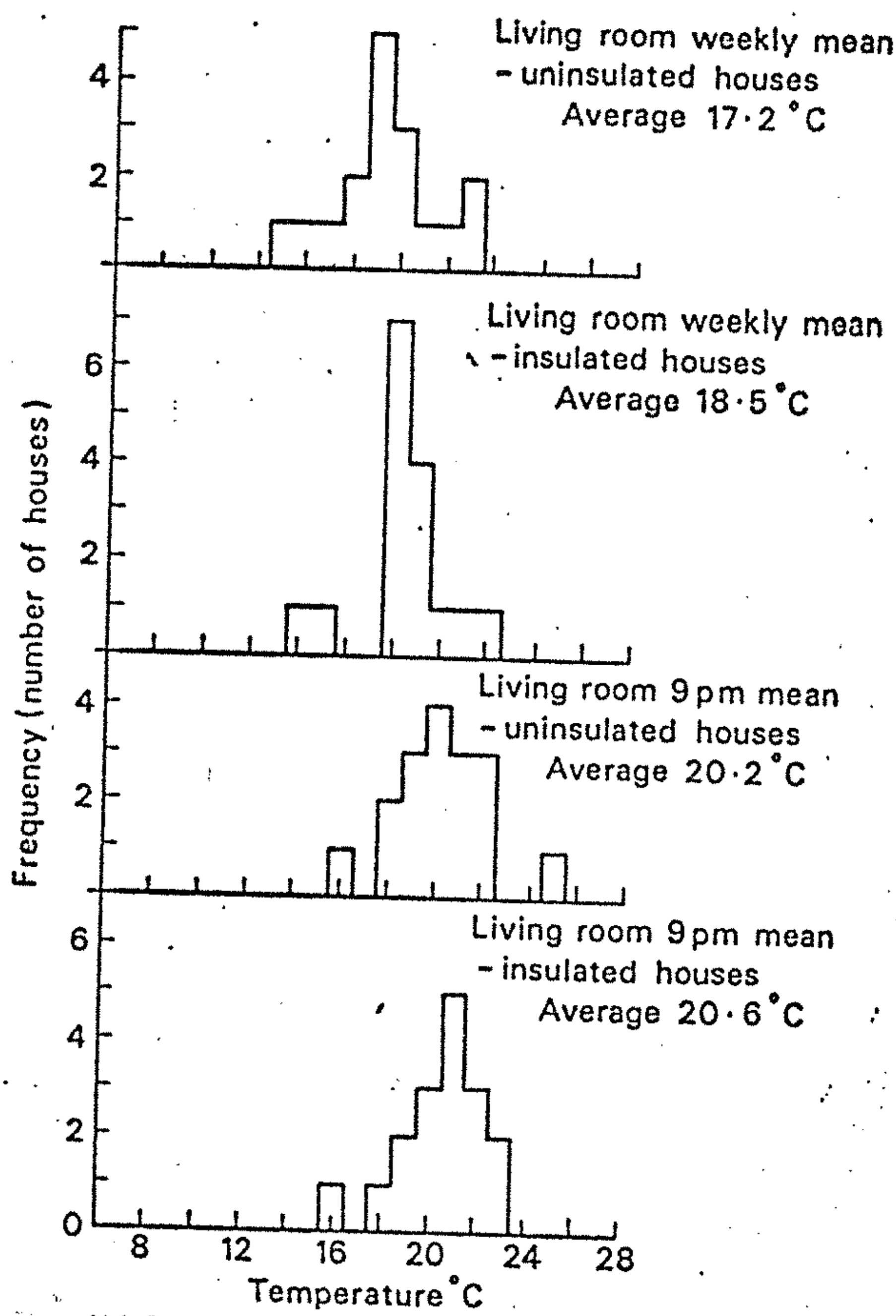
WHITBURN

5 person terrace house



electric under floor heating.

FIGURE A.1.2. - Distribution of weekly and 9 pm mean temperatures for living rooms



Distributions of weekly and 9 pm mean temperatures for living

FIGURE A.1.3. - Distributions of weekly mean temperatures for bedrooms and whole house

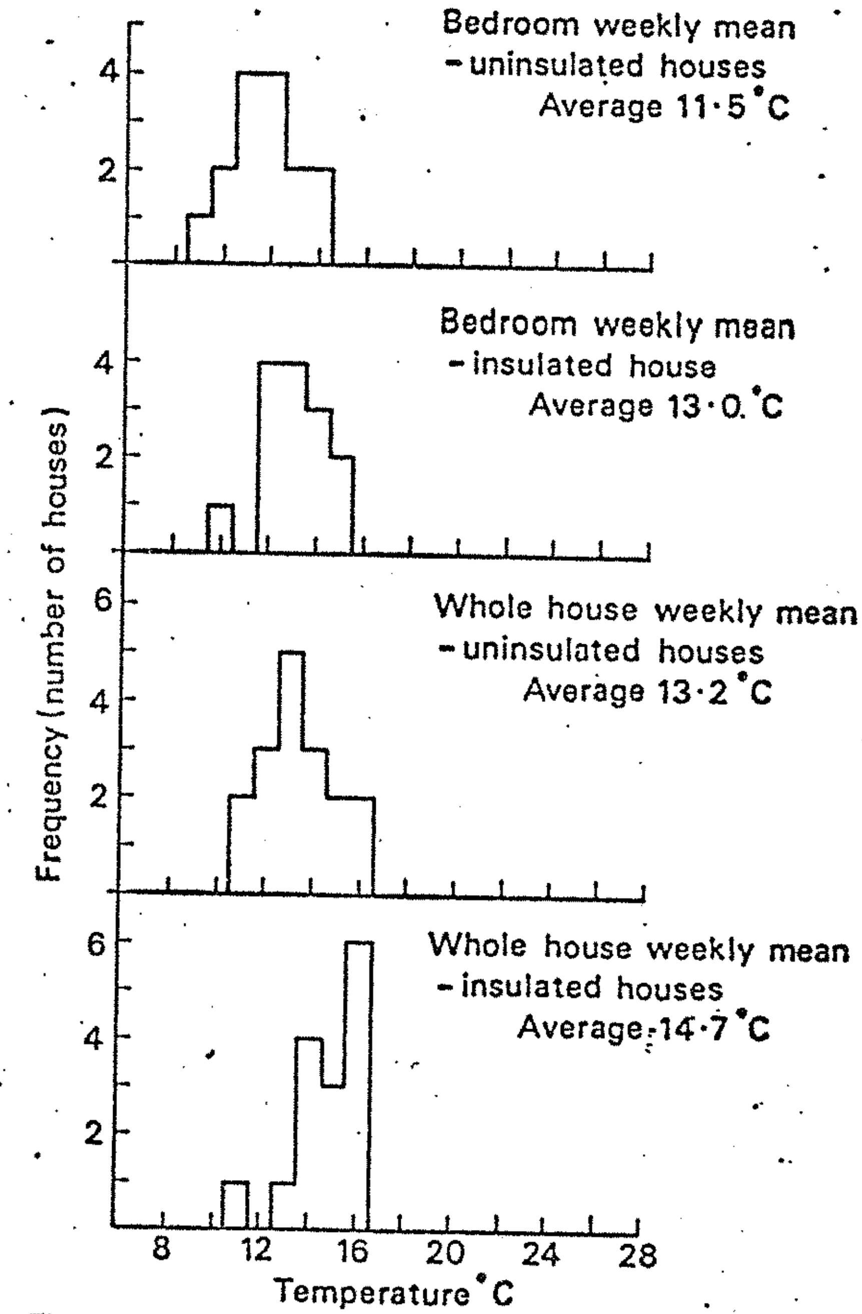


Figure 6(b) Distributions of weekly mean temperatures for bedroom and whole house: from recordings made in December 1974 and January 1975

A/2. HAMILTON

1. Hamilton is a large industrial town satellite to Glasgow, at a similar altitude to that of Glasgow.

Hamilton dwellings

2. The BIH project used a local authority estate of 2-storey flats undergoing rehabilitation. There are four flats to each block, two up and two down, built in 1934. (Figure A.2.1). The rehabilitation work included new heating systems, but no improvement to the windows, which are probably draughty. The flats are of traditional cavity wall construction, rendered or part-rendered, with tiled roofs. Cavities of the 20 test flats were filled with UF foam, and their roofs insulated with 100mm glass fibre on top of 25mm already there.

Tenants

3. The sizes and structures of tenant's households are mixed, and they have well below average income. Social analysis showed an imbalance in family size, between groups, sufficient to require correction by adjusting fuel consumption figures. Mean household sizes were 3.1 and 2.3, allowing for 'correction' of the annual gas consumption by 5.8 GJ net. This represents 92 therms at 60% efficiency.

Heating etc.

4. Heating is by gas radiant fire (manually controlled) in living rooms, and a gas fired radiator system elsewhere with the boilers providing hot water also. The radiator system is governed by a thermostat in the hall. The combined output of the boiler and fire together are about 15 kW as against design heat losses of 5 and 3.5 kW for control and test dwellings respectively. Such system oversizing could lead to reduced boiler efficiency which should be worse in the test flats, but it is not possible to prove or disprove this thesis. Rated efficiencies were 73% and 61% for boiler and fire respectively. (Table 1.1 assume 60% average).

Temperatures

5. Temperatures were monitored with thermohygrographs for one-week periods during January and February 1975 and some dwellings again in March 1976. Also the living rooms of two pairs of flats were monitored continuously for 7 weeks in January/February 1975. Outside temperatures measured at East Kilbride (10 kms away) were regarded as valid for Hamilton. The temperatures recorded are summarised in Figure A.2.1. (BRE Draft Report 'Field studies on the effect of increased thermal insulation in some gas heated houses').

Results

6. The test flats were significantly warmer than the control flats, even in living rooms at 9 p.m. There could have been voluntary decisions to take some of the benefits of insulation in the form of more warmth. However, insofar as the average temperatures for some of each group of dwellings were influenced by the central heating thermostats, i.e. except where gas fires

only were used, there would have been higher temperatures in the kitchen and bedrooms, after insulation, for the same thermostat setting in the Hall. The thermostat would not be calling for substantially less heat from the boiler, since the hall being an internal space, would be only indirectly (i.e. via raised temperatures in perimeter rooms) affected by the insulation. The temperatures of living rooms on the other hand, should have been controllable, provided the gas fires could be put on low enough settings. The temperatures recorded in bedrooms (Table A.2.1) leave the impression that in most flats the central heating was not normally used. So it ought to have been possible to provide such heat as was wanted much more economically than this. It is necessary to conclude that the temperature increases were perhaps partly voluntary, with no way of estimating the size of the part. Here again, therefore, it seems likely that such energy savings as were achieved (in relation to household sizes) were considerably less than should have been the case, had effective control of temperatures been possible.

TABLE A.2.1. - MEAN WEEKLY TEMPERATURES AND FUEL CONSUMPTIONS (HAMILTON)

	Uninsulated houses		Insulated houses	
	1st visit 1975	2nd visit 1976	1st visit 1975	2nd visit 1976
Temperature in degC:				
Living room	17.6 (18.1)	18.3	19.3 (19.9)	20.3
Living room 9p.m.	19.5 (19.9)	20.1	21.0 (21.7)	22.2
Bedroom 1	12.6 (12.4)	12.9	13.9 (14.7)	14.3
Kitchen	16.5		18.7	
House average	14.6 (14.7)	15.1	16.2 (16.9)	16.7
External	3.4	3.7	3.4	3.7
Fuel consumptions in GJ:				
Gas input	1.73 (1.87)	1.70	1.69 (1.73)	1.74
0.7 x gas	1.21 (1.31)	1.19	1.18 (1.21)	1.21
Electricity	0.15 (0.18)	0.14	0.14 (0.18)	0.16
0.7 x gas + elect.	1.36 (1.49)	1.33	1.32 (1.39)	1.37

1st visit January/February 1975; 2nd visit March 1976.

House average temperatures are obtained from the mean values in each room weighted by the volume of the room, assuming the temperatures in the hall and bedroom 2 are the same as in bedroom 1. This was found to correspond very closely with 0.4LR + 0.6TB1 and this expression was used for the second visit when measurements were not made in kitchens.

Results from 15 uninsulated houses and 15 insulated houses on 1st visit, and from 8 of each group on 2nd visit. Figures in brackets under 1st visit are averages over the 8 houses included in the 2nd visit.

Note consumptions <u>not</u> corrected for differences in household size.

(Source - BRE Draft Report (unpublished).

A/3. PLYMOUTH

The houses

Tenants

1. The Deer Park estate is to the north-east of Plymouth at an altitude of about 100m, but in micro-climate is probably typical of Plymouth as a whole, except that being on a North-facing slope it gets less winter sunshine than most places because of overshadowing. (This factor was not measured). The mildness of the area showed in very modest fuel consumption compared with other sites. The project involved 20 test and 17 control dwellings built in the late 60s to 1965 standards of insulation. They are 3-bedroom, 2-storey houses in short terraces, of concrete block cavity construction, rendered externally (Figure A.3.1). In the test houses, external walls were cavity filled with rock fibre, and roofs insulated with 75mm glass fibre on top of the existing 25mm of polystyrene beads. Calculated % reduction in total heat losses was 22%. It is a local authority estate, with a mixture of household sizes and structures, and incomes about average or maybe a little above (a few tenants have been buying their houses). Most of the houses are heated by gas fired warm air systems, with outlets downstairs only but including one in the hall. Control of these is by thermostat in the living room and by adjustment of register flaps. The remainder of the houses are not connected to gas, and heat by on-peak electricity with fixed living room fires and occasional portable heaters. All hot water was by electric immersion heater at the time of the project.

Monitoring

2. Monitoring was continuous from January 1975 until April 1977, though the monitoring of temperature in individual houses was intermittent due to planned rotation of the multi-channel chart recorders and to an inevitable ration of technical hitches. Measurements included in each house 4 room temperatures (living room, hall, kitchen, main bedroom) together with weekly readings of main gas and electric meters a cooker meter and an 'house run' counter on the immersion heater. External temperatures were read in at least two places on the site, and windspeeds recorded daily with a hand-held anemometer (to be checked against those of the local Met. station). The standard questionnaire was circulated in the spring of 1975, 76 and 77.

3. Recorded temperatures (see Table A.3.1) showed that:

(a) by and large gas heated houses were warmer than electric

(b) test houses were warmer than control, both upstairs and down.

The relatively low temperatures of all-electric houses has yet to be studied: the same phenomenon occurred at Washington (and at Whitburn). It may be due to awareness of the cost of the fuel, or possibly because electric radiant fires give comfort at lower temperatures, the latter climbing only slowly as the structure warms up.

Thermostats

4. It was observed in calculation that while the effect of the insulation on the whole house was around 22% reduction in heat loss, that on the living room was only 8% in mid-terrace houses. Since thermostats were in living rooms, in theory little more than 8% less heat would have been called for, to keep these rooms at the same temperature as before, and other rooms would have become warmer except insofar as warm air registers allowed for crude control of distribution. Measured temperatures seem to lend support to this theory but it is difficult to prove. There is also the fact that all other things being equal, upstairs temperatures ought to have been higher, in test houses, in relation to downstairs ones, through internal heat transfer as at Whitburn. However, at Plymouth there was some scope to control this transfer, as a separate analysis seems to bear out. (CP 56/75 sets out a theoretical basis for estimating vertical heat transfers in houses in the context of insulation).

Room moisture content

5. Surveys of the moisture content of roof timbers in eighteen of the houses were made in Spring and Autumn 1977. These indicated no danger of damage from condensation except in only three roofs were eaves ventilation had been blocked by the insulation, and the timber moisture content was above 20% (in one case 28%). One well-ventilated roof had moisture content of 16% at all 21 testing points.

Cavity wall problems

6. Prior to installing the insulation, all the houses were surveyed to identify damp problems in external walls. All of these were put right. The chief cause was briding of cavities by mortar on ties or at the bases of walls, above DPC's. After filling, two or three additional damp patches were reported where to the tenants' recollection there had been none before. Walls were opened up, to reveal more cavity bridging. It appeared that the cavity filling had turned critical certain faults that had hitherto been non-critical. It should be stressed that the site had extremes of driving rain and clearly the walls had been carelessly built.

Results

7. Figure 2.3 shows for comparison the mean total gas consumption of test and control groups (scale irrelevant) overlaid on mean external temperatures. There are weeks in which the expected correlation is absent. This seems to be because wind has a large effect on energy consumption, but especially so in these houses when it blows from particular directions. The same observation has been made in respect of the Abertridwr houses, and is clearly a factor that might be designed against in future. (Plymouth data is inadequate for accurate comparison of temperatures and windspeeds as, while the latter are available daily, consumptions were recorded only weekly, thus preventing comparison with windspeed and direction, which phenomena tend to last only 2 or 3 days).

TABLE A.3.1. - MEASURED TEMPERATURES (PLYMOUTH)

13-week period 1 December - 29th February

The following average temperatures were measured over a 13-week period 1st December to 29th February (all readings in degC).

	Living rooms	Kitchens	Halls	Bedroom 1
All control houses	16.95	18.57	13.62	12.97
All test houses	18.84	19.77	18.83	15.00

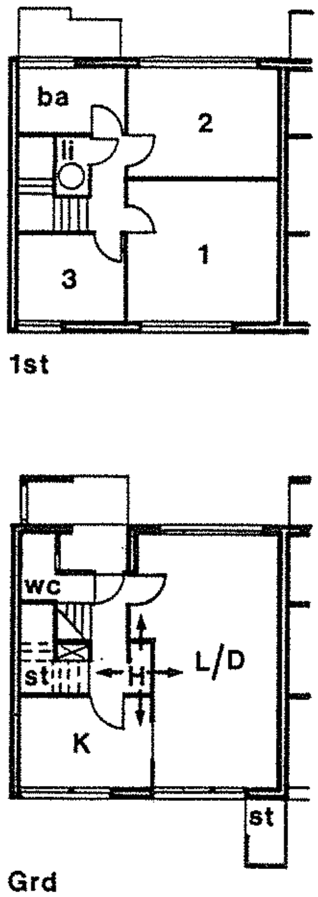
	Living rooms	Kitchens	Halls	Bedroom 1
Gas control	17.76	20.81	16.87*	13.95
Electric control	14.96	13.32	12.03*	10.31
Gas Test	18.89	20.28	18.83	15.18
Electric Test	18.06*	13.41*	n.a.	12.12*

* very small samples - not reliable

FIGURE A.3.1. - PLYMOUTH - 5 PERSON TERRACE HOUSE

PLYMOUTH

5 person terrace house



A/4. COVENTRY

1. A new built local authority project on a flat site north-west of Coventry City - elevation about 60m. 20 test and 20 control houses, all 3-bedroom 2-storey dwellings on short terraces, facing east-west. All are of brickclad timber frame construction (gable walls brick/cavity/block) with tiled roofs and solid concrete floors (Figures A.4.1 and A.4.2).

Dwellings

2. All houses are heated by ga-fired radiator systems on both floors, with integral domestic water heating and an additional gas radiant fire in each living room as well as radiators. CH systems have night set-back facility, but no time-clock, and all radiators have a TRV. Each house was fitted with a powered ventilation system drawing air from the loft, and a non-closable ventilator in each room relieves the pressure. The living rooms have also a large, high level, mandatory ventilator. Cooking is by gas or electricity at tenants' choice.

Construction

3. Control houses are insulated to approximately the 1975 Regulation levels, with 50mm quilt in roofs and 25mm in walls. Test houses are better than other BIH projects, with 100mm quilt in roofs and 75mm in walls, and incorporate polythene vapour barriers in all external surfaces (Figure A.4.2). Test house gable walls are UF foam cavity filled and ground floor slabs have edge insulation. 10 of the test houses have double glazing throughout. Calculated heat losses are 16% less in single glazed test houses and 28% less in double glazed ones.

Tenants

4. The tenants have, on average, lower incomes than most other BIH estates. Also, a large proportion consists of households with small children, as might be expected on a new estate. The latter factor probably contributes to a high 'energy need' (especially in relation to income) such that consumption of both gas and electricity were greater than those of any other BIH estate, despite the higher standards of insulation.

Monitoring

5. Temperature monitoring started as houses became occupied (summer 1975) and continued (winters only) until May 1977, with further, limited monitoring until September 1977. Multi-channel chart recorders observed temperatures in all living rooms at 5 minute intervals. In addition, 3 thermohygrographs per house operated for 3-week periods in mixed groups of houses on rota, normally repeating at least 3 times per heating season. Electric and gas meters were read weekly in all houses from summer 1975 to September 1977.

6. Each house was wired up for the remote reading of moisture probes built into structural timber. These were read, from a junction box under the eaves, quarterly for two years. BRE took tracer gas tests of air leakage in relation to outside windspeed over a period of 6 weeks. Social Surveys were mounted in the early summer of 1976 and 1977.

Results

7. The comparison, between groups, of fuel consumption shows a healthy difference between the averages of test and control groups (Figure A.4.3). As compared with the calculated insulation differences between groups the realised consumption seem to have been proportionately more affected by the wall and roof insulation than by the double glazing. This has yet to be explained.

8. Consumption of electricity has been high in all houses - 2500kWh per annum average in all houses without electric cooking, and 3300 in those with. These ought to have had an influence on space heating consumption, which will emerge when heat balance computations are complete. Metabolic gains should also be relatively high, from large households, many at home all day. Solar gain should be modest because the houses all face East-West.

Temperatures

9. The whole-house heating systems would have been partially responsible for comparatively high bedroom temperatures. Some households heated their bedrooms overnight for the benefit of children (Table A.4.1). In many others, due to the response of bedroom temperatures to those downstairs, it was apparent that heat rising within the home, <u>at times of downstairs peaks in temperatures,</u> was often sufficient to over-ride upstairs TRV's and cause bedroom temperatures to rise above those of their thermostat settings. There is evidence from this project to suggest that with the higher levels of insulation, heat emitters in bedrooms are not necessary at all, although people may need occasional extra bedroom heating for particular circumstances.

10. Averages of measured temperatures (Table A.4.1) suggest that far from the test houses being warmer as at other projects, in this case they were cooler. The data is rather inconsistent on this score, so it can not be claimed confidently that warmer wall and window surfaces in the two test groups made for comfort at lower air temperatures. Possibly the temperatures achieved constitute 'saturation' comfort levels - extra insulation did not itself generate higher temperatures - or it could be said that the TRV's were doing their job. But there is some evidence that the TRV's were not properly understood, and it could well be many of these houses, in <u>both</u> groups, were run warmer than the tenants really wanted them. Study of temperatures from Coventry will continue.

Ventilation

11. The air change rate study showed that the ventilation system had a serious weakness. The ventilation rate is very sensitive to outside windspeed, and while the design minimum was maintained at low windspeeds, above a windspeed less than the median for the site, these would always be more than one air change per hour. So energy is being lost unnecessarily rather more than half the time, and this would help cause an unnecessarily high fuel consumption. In fact, since the houses were first occupied, most of the ventilation fans have been switched off. A few had developed faults, but in most cases the tenants chose to do without them on the grounds that their noise or vibration were

irritating, or were unwilling to pay for the running cost (the same happened at the Washington site). Apparently, while in calm weather the fan ensures a regular minimum air change rate, once the outside wind takes over, it is redundant, and the house is cross ventilated through the fixed ventilators in windows, and through any other structural leakage. Understandably, the houses are reported to be draughty - and may well have been run a little warmer to compensate. Finally, the disused fans are mounted over a register in the ceiling of the stairwell, and these would allow a lot of costly air leakage into the loft space.

Structural moisture

12. The monitoring of moisture content in structural timbers showed no cause for alarm; only sole plates had over 20% moisture content, and these are of treated timber. However, recent work by BRE's Princes Risboro Laboratory has shown that walls of timber frame construction tend to be inherently leaky to air. It may be that air penetrating external walls is protecting the structural timber from damp. Certainly the vapour check membranes were not generally airtight enough to prevent interstitial condensation.

13. In conclusion, while the Coventry project looks successful in terms of energy saved by the insulation, the pleasing comparison between the test and control houses may well conceal certain quite unnecessary energy-wasting features common to both groups. Realised total heat loss rates can be estimated from temperature and consumption data - but very roughly.

TABLE A.4.1. - MEASURED TEMPERATURES - COVENTRY

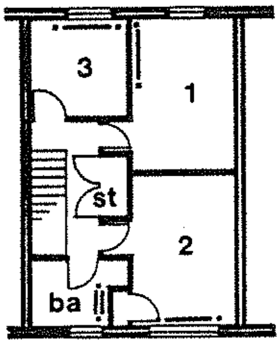
Mean room temperatures sampled regularly throughout ..3-week periods during September - April gave the following average figures:

	Living Rooms	Bedroom 1	Bedroom 2
Control houses	19.9degC	18.7degC	17.0degC
Single glazed test	19.0degC	19.5degC	17.9degC
Double glazed test	18.2degC	16.1degC	16.4degC

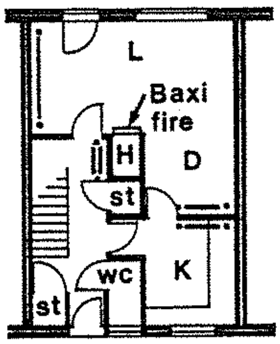
<u>FIGURE A.4.1. - COVENTRY - 5 PERSON CENTRE TERRACE HOUSE</u>

COVENTRY

5 person centre terrace house



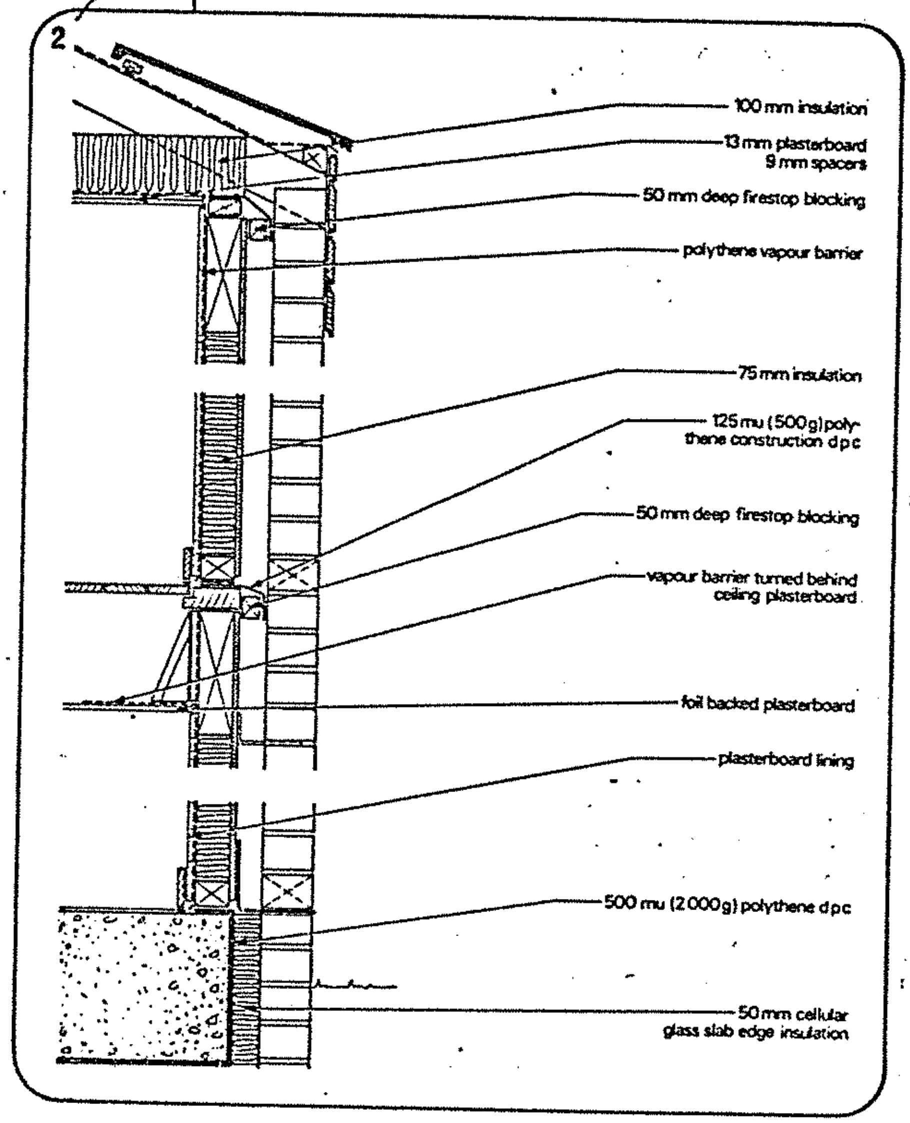
1st

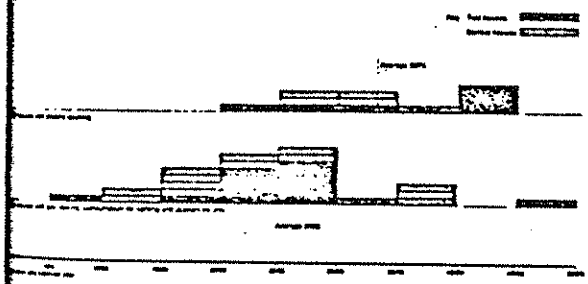


Grd

FIGURE A.4.2. - Constructional Details

Remove box and No "2"





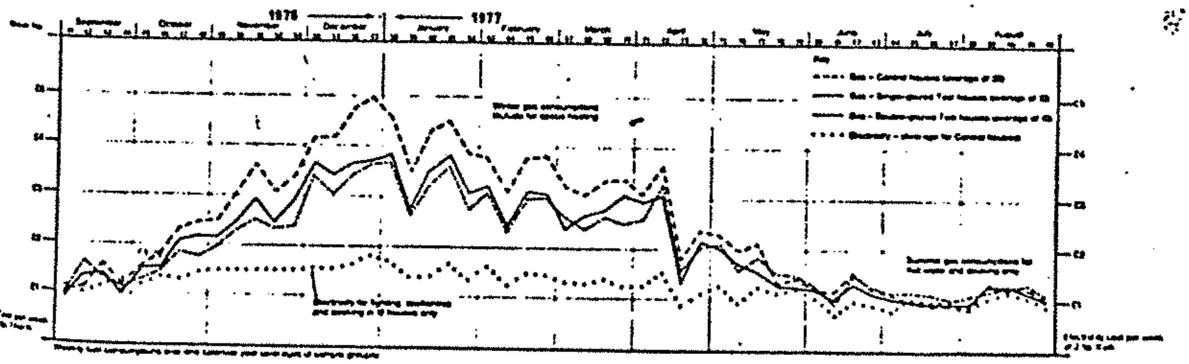
ectricity consumptions of control and test houses (grouped by ethod of cooking) 31.8.76–29.8.77.

The diagram at left summarises electricity consumptions for 'Test' and 'Control' houses over one calendar year, grouped to separate those with electric cooking.

The difference in electricity consumption between the average of 'Test' and 'Control' houses was insignificant (2810 as against 2703).

Weekly energy consumptions measured over a one year period are shown below, as averages for each of the groups of houses. The electricity consumptions for the 'Control' houses are reasonably representative of all groups. Differences between the averages for gas consumption show the effect of the insulation and double glazing.

The graph also shows the rise and fall of weekly energy consumption and costs through the seasons. The vertical scales (for gas and electricity) also indicate the energy cost per week based on the present unit rate for each fuel (2·5p/Kwh and 15·3p/Therm).



A/5. - DARLINGTON

Dwellings

1. The Darlington project consists of two similar blocks of old persons' 'sheltered flats' in villages 4-5 miles apart in the Tees valley, Middleton Street, George and Hurworth, whose altitudes are 46 and 38 respectively above sea level. The test and control blocks were built in 1968 and 1972, and each has 2 storeys and load bearing cavity wall construction with concrete floors. The plans differ a little, but each contains very similar one and two person flats, with a fairly wide range of heat losses within each block (Figures A.5.1 and A.5.2). The control block, Dinsdale Court, Middleton, is of pre-1974 insulation standard but with 100mm of quilt roof insulation. It has metal framed windows with controllable vent slots. The test block, Linden Court, Hurworth, has large timber framed windows incorporating glass louvre opening lights, and floor to ceiling windows in the living rooms. These were double glazed, the roof insulated with 100mm quilt and the walls cavity filled with UF foam.

Tenants

2. The tenants are all elderly, though of some couples one partner is still working. Mobility varies - some are semi-invalid and confined to a chair, others go out regularly, and there are communal rooms in the blocks, including some catering, and clothes washing facilities. So energy uses can be expected to vary a lot between flats. It is also relevant that corridors are heated, as some tenants can economise by admitting this warmth to their flat.

Heating

3. The flats are all-electric. Both blocks have electric ceiling heating, and electric bar fires as well. Many never use the ceiling heating: very few use it all the time. Water is heated by immersion heaters, and other principal energy uses being for cooking and television.

Monitoring

4. Temperatures were monitored hourly in each room, the corridor and externally. In addition a small number of extra censors read temperature gradients at 3 places in height and depth of the room. All data was logged centrally in each block, for most of 52 consecutive weeks September 1975 - August 1976. Electricity consumption was recorded weekly for a full year, but could show no distinction between uses. Solar radiation was also recorded at site: sunshine could well be a relatively large proportion of total heat input (Estimated about 30%).

Results

5. The difference in total heat loss between the average of test and control flats is about 24% (at the 'design temperatures'). The mean annual consumption of electricity was 14.2% less in the test block, estimated as some 24% saving in space heating costs, by deduction of a non-heating 'base load' at the consumption rate for high summer. Calculation is difficult as 'heating seasons'

are ill-defined, and differ between flats.

Temperatures

6. There was also a difference in average inside temperature, between the two groups of flats, amounting to about 1.8degC, or 18% of the average inside-outside temperature difference of 9.9degC for the control flats. External temperatures appeared to be higher at the site of the Test houses, by about 0.5degC over the heating season, which could be due either to micro-climte or instrument error. The former seems more likely since solar radiation is consistently greater at the Control site - suggesting the Test site has consistently more local cloud cover (see Figures A.5.4 and A.5.5).

7. The recorded internal temperatures are summarised in Figure A.5.3 These temperatures were tenant-controlled insofar as room control of temperatures was possible. But only the small minority who used ceiling heating - two test and five control flats - had the benefit of thermostatic control.

8. As well as having higher internal temperatures, the test flats also had a longer heating season, the averages for the two groups being approximately 38 and 36 weekly respectively. This unexpected result suggests that Test flat occupants became acclimatised to their higher living temperatures. But sunshine differences may have entered into it. Temperature gradient data is summarised in Figure A.5.6. This indicates the effect on the gradients of the double glazing in the test flats, and incidentally the effect of floor slabs of ground floor flats on the distribution of temperatures.

9. No technical problems were apparent with the insulation. Some of the double glazing, however, in vertical sliding sash secondary windows, proved unsuitable for use by elderly people. The sashes were not counter-balanced, but held by spring loaded catches. The awkwardness of the catch releases the weight of the sashes and the fear of dropping them combined to inhibit their use entirely in many flats.

FIGURE A.5.1. - DARLINGTON - LINDEN COURT

DARLINGTON

Linden Court

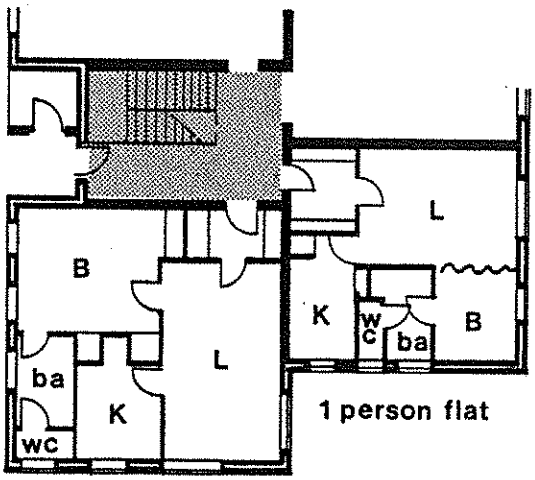
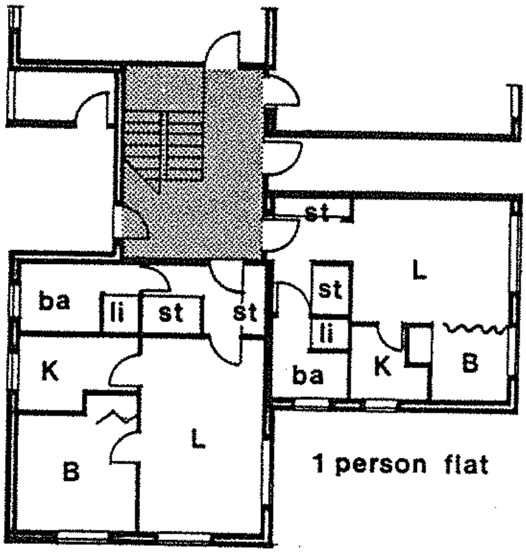


FIGURE A.5.1. - DARLINGTON - DINSDALE COURT

DARLINGTON

Dinsdale Court



2 person flat

FIGURE A.5.3. - DARLINGTON - LIVINGROOM KITCHEN BEDROOM AND AVERAGE INTERNAL TEMPERATURES

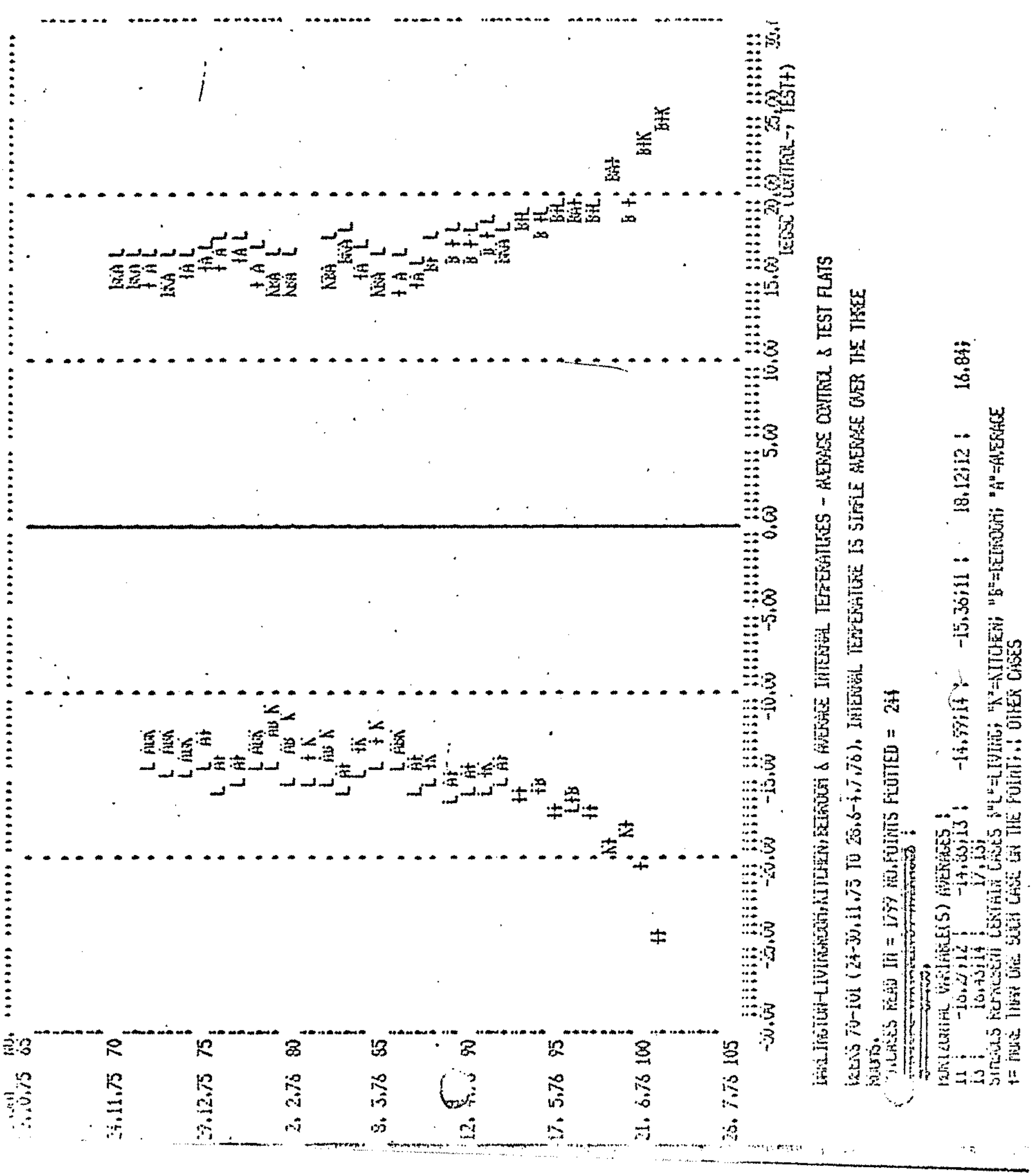
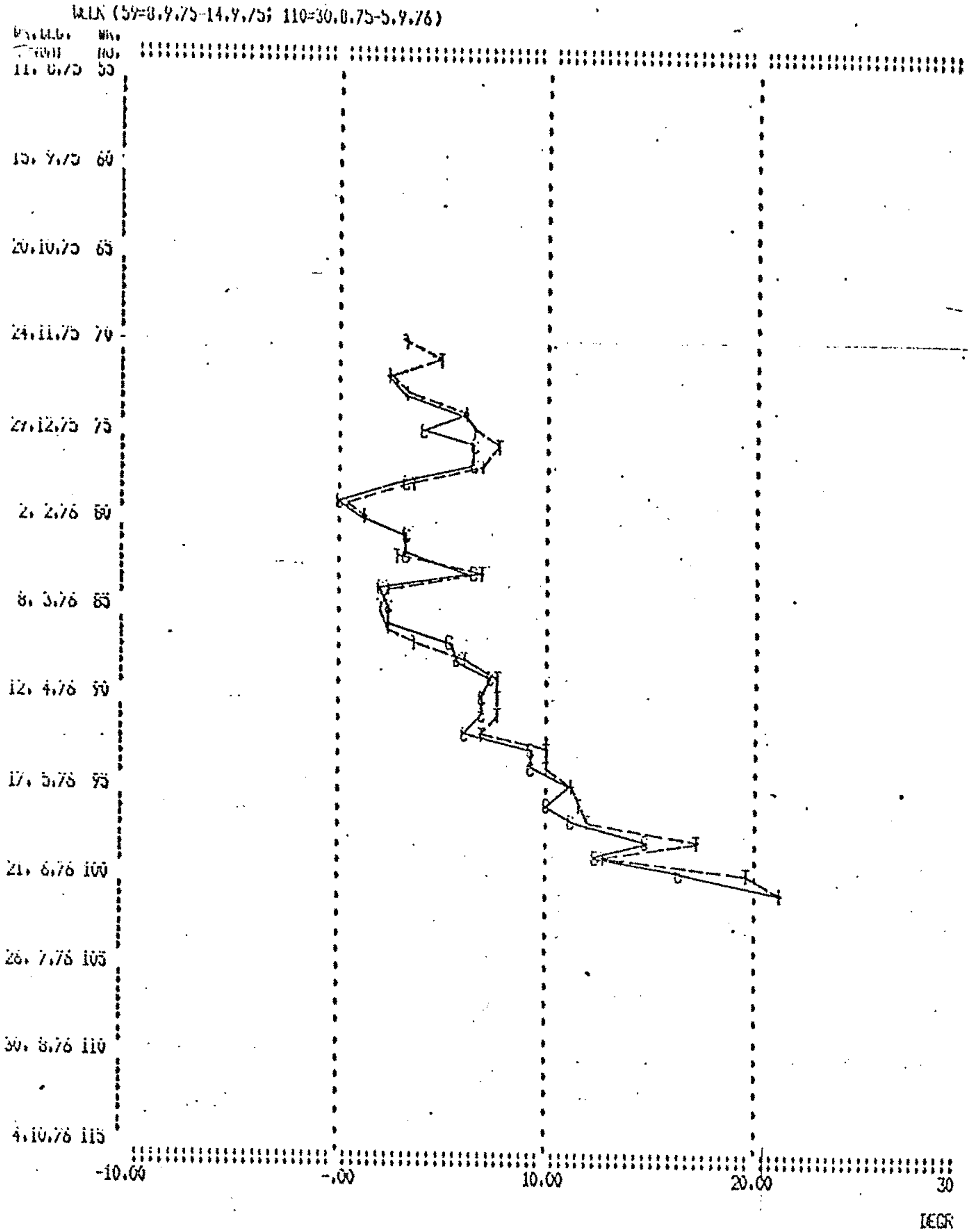


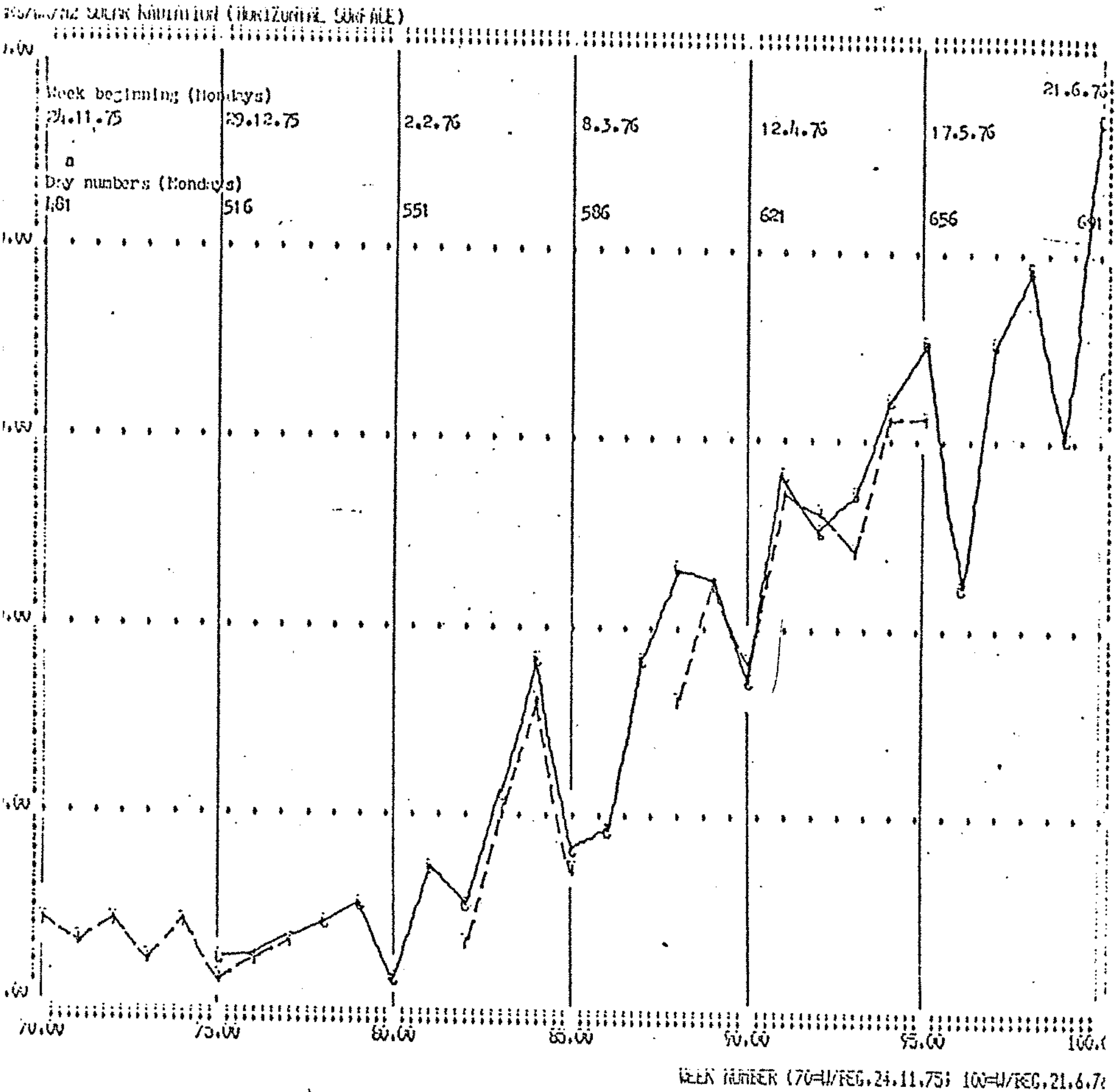
FIGURE A.5.4. - DARLINGTON - AVERAGE WEEKLY EXTERNAL TEMPERATURES



DARLINGTON AVERAGE WEEKLY EXTERNAL TEMPERATURES FOCONTROL AND TEST GROUPS. WEEKS BEG. 8.9.75-30.8.76

THESE ARE 37 IN DINSDALE(CONTROL) AND LINDEN(TEST) COTS, HAVE ELECTRIC CEILING HEATING, IN A 2-STOREY
BLOCK. FLATS ASSUMED TO BE UNOCCUPIED (THOSE WITH 0 CONSUMPTIONS) HAVE BEEN OMITTED FROM THE AVERAGE
NO.CASES IN DATA = 3060; NO.PLOTTED = 61; NO.CASES WITH MISSING VALUES : 43
OTHER CASES BEYOND SPECIFIED RANGES
(INTERVALS-VERTICAL, HORIZONTAL : 7.04)
SYMBOLS REPRESENT CERTAIN CASES : C = CONTROL FLATS; T = TEST FLATS
*= MORE THAN ONE SUCH CASE ON THE POINT; : OTHER CASES

FIGURE A.5.5. - DARLINGTON - WEEKLY SOLAR RADIATION



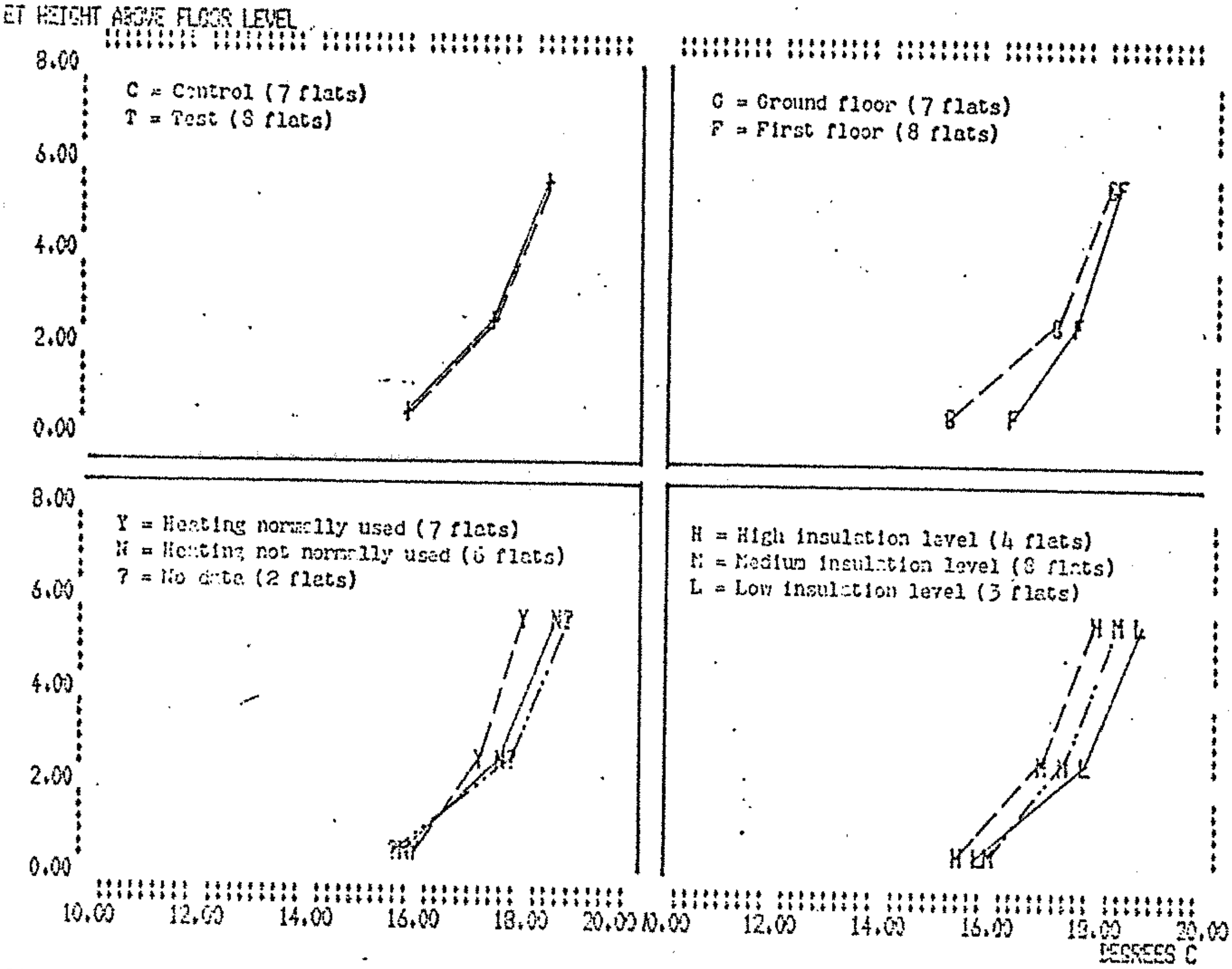
...INGTON-WEEKLY SOLAR RADIATION - DINSDALE & LINDEN COURTS, WEEKS 70-100 (W/BEG. 24.11.75-21.6.76)

...COURT IS CONTROL FLATS, LINDEN COURT, TEST, ~~DATA FOR DINSDALE COURT ...~~
... DATA ARE COMPLETE, DATA FROM DASHDO1,
CASES READ IN = 8041 NO.POINTS PLOTTED = 46

...S REPRESENT CERTAIN CASES (C=DINSDALE COURT(CONTROL); T=LINDEN COURT(TEST)

PLOT5

FIGURE A.5.6. - DARLINGTON - 9PM LIVING ROOM VERTICAL TEMPERATURE GRADIENTS



DARLINGTON 9PM LIVINGROOM VERTICAL TEMPERATURE GRADIENTS, 84 DAYS BETWEEN FEBRARY & JUNE 1976

MOST POINTS AVERAGED OVER INNER & OUTER LOCATIONS, EX DATH7D09 VIA ALL9PMGRPD.

NO.CASES READ IN = 10; NO.POINTS PLOTTED = 30
SYMBOLS REPRESENT CERTAIN CASES -(SEE NOTES ON PLOTS)
F= MORE THAN ONE SUCH CASE ON THE POINT; ,=OTHER CASES

JHR/HRD/DOE 30/03/81 ALL9PMGRPD

A/6. WASHINGTON

1. Glebe village is a neighbourhood of Washington New Town (Co. Durham) at an altitude of about 70m above sea level, and in the zone represented by 2326 degree-days.

The 33 houses constituting this project were purpose designed by the Project Office of the University of Newcastle upon Tyne. They were built 1975-76, and monitored, by the Building Science section of the University's Department of Architecture, from 1977-79. These 5-person 2-storey houses in short terraces (Figure A.6.1) are all insulated to the same standard - approximately that of Test houses in the rest of the programme. Their calculated heat losses are 180-197 Watts per degC at 1.25 air changes per hour (for middle - and end - terrace houses).

Construction

2. (See Figure A.6.2). Party walls and gable walls are of load-bearing blockwork, and front and rear elevations of timber frame construction insulated with 100mm of glass fibre. Roofs have 100mm of glass fibre between joists, and are ventilated to outside. Gable walls are cavity filled with 50mm glass fibre batts. Ground floors have vertical perimeter insulation of expanded PVC. All windows are double glazed, in GRP frames with neoprene gaskets.

Ventilation

3. Mechanical (whole-house) ventilation was provided in half of the number, to give 0.75 a.c.h. in bedrooms and 1.0 in living rooms. Bathrooms and utility rooms (both internal) have a common powered extract system operated by the light switches, and the utility has an additional fan to cope with high humidity. The whole-house systems are of the input type, as for Coventry but with air supply ducted to each room. Small slot-type hit-and-miss ventilators were provided also to all houses, and these are closable. Kitchens have a manually switched extract fan. Many of the whole-house systems were switched off by the tenants, largely to save electricity. This may have proved to be a false economy in that the ducted systems inhibited internal air movement by stack effect, and without them the whole-house ventilation rate became greater. (In fact it is not yet known whether the increase in ventilation heat loss outweighed the saving in fan running cost - but the latter should have been largely recouped in the form of useful heat. BRE are sceptical about these theories).

4. A survey of ventilation habits revealed that out of 30 households, 19 definitely made use of the adjustable slot ventilators as part of their routine. Of the remainder:

- 2 relied on the mechanical system only;
- 2 used the mechanical system plus windows;
- 1 used no ventilation, apart from extract fans, and
- 5 used windows only.

Heating

5. The heating arrangements consist of electric panel heaters with individual thermostats, the whole system having both time clock and zone control. It was designed for 'continuous' heating, exploiting the relatively heavy house structure, together with an overnight off-peak tariff, to store cheap energy. Table A.6.1 shows the connected load of heaters originally installed and as modified to allow for the intermittent heating pattern adopted by most households, using largely on-peak current. The houses had been designed before the price difference between gas and electricity as a space heating fuel became expressed in their tariffs. Electricity had the advantages of easy and cheap control and simpler monitoring of consumption.

Fuel price

6. Large increases in the tariffs for electricity, between the time the houses were designed and when they became occupied, resulted in the tenants trying hard to economise, and thus finding the houses not very comfortable. With such small fabric heat losses, cold draughts from minor structural defects, room temperature gradients, cold party walls and floors and air movement within the houses were all more acutely felt than in a thermally 'conventional' house. The modifications noted in Figure A.6.1 gave satisfaction, largely by increasing the amount of radiant heat in the living room and also by speeding its warm-up.

Energy consumption

7. Measured energy consumption is shown in Figure A.6.3. Several houses had to be removed from the sample because their tenants had chosen to use paraffin or bottled gas heaters, whose fuel could not be monitored. The total consumption for all purposes is very modest, and the space heating, even if all the power had been drawn at the on-peak rate, does not compare badly in cost with that of the test houses at other BIH projects. (About £71 per week round the year, at 3.0p/kWh excluding radiant fires. Total electricity £281 p.a.).

Temperatures

8. However, the whole-house average air temperatures, with a mean of 14.5degC and range 12.8degC to 16.4degC, are low. Temperature gradients will need to be studied before conclusions can be drawn about the perceived standard of comfort, since the superior controllability of this form of heating and its large radiant component could well make for acceptable comfort at relatively low average air temperatures.

9. The University's conclusions from their analyses of the Washington project have included the following:

(a) the 'heat sink' effect of heavy party walls and an insulated ground floor slab can be severe: the latter is especially problematic for the first year, until it dries out, and less so thereafter if carpeted. The party wall creates problems where the adjacent space is unheated. Ideally, party walls should be cavity filled where heating is continuous or 'high/low'; and dry lined where heating is intermittent.

(b) Double glazing is probably justified on grounds of comfort where there would otherwise be a sharp contrast between wall and window temperature.

(c) Weak points with regard to airtightness include all dry joints, and door and window subframes.

(d) High thermal capacity is useful in general in providing even temperatures and utilizing solar gains, but causes problems if used with an 'on-off' heating system. In such a house, a 'high/low' system is essential, preferably one that can not readily be switched off at all. Houses with on/off heating must have relatively low thermal capacity.

(e) Partially out of Washington experience a natural ventilation system has been designed by the University's Building Science Section, consisting of small-scale pipes (about 30/50mm dia.) from each room to a single roof terminal raised about aerodynamic pressure zones. It extracts by stack effect only. In HDD's view this would still need to be controllable by the household (which should not be difficult to arrange) and both parties agreed that the design of its roof terminal is critical, in that this must be unaffected by windspeed or direction. BRE are sceptical about the proposal.

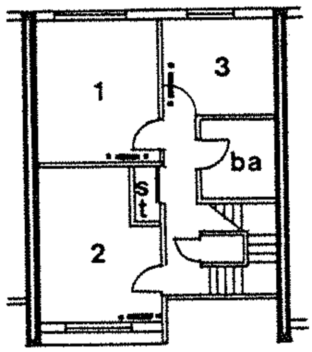
TABLE A.6.1. SUMMARY OF INDIVIDUAL ROOM HEAT LOSSES AND INSTALLED LOAD

Room	Heat loss W/degC	Assumed Vent rate AC/hr	Design Temp degC	Calculated Heat Loss W	Installed Load W	Modified to:
Living room	43.83	1.75	21	964	2 x 600	
Dining room/ Kitchen	48.79	1.5	21	1073	1 x 600 1 x 800	600 + 750 1940
Utility	4.64	0.25	16	79	-	= radiant
Bathroom	4.68	0.25	22	108	-	
Hall	30.31	1.75	16	515	600	
Landing	21.41	1.5	16	364	800	
Bedroom 1	25.93	1.5	16	441	600	
Bedroom 2	27.05	1.5	16	460	600	
Bedroom 3	17.79	1.5	16	302	600	

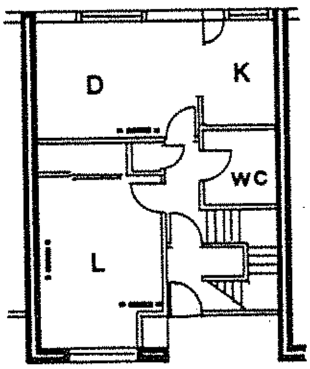
FIGURE A.6.1. - WASHINGTON - 5 PERSON TERRACE HOUSE

WASHINGTON

5 person terrace house



1st



Grd

FIGURE A.6.2. - TYPICAL HOUSE SECTION

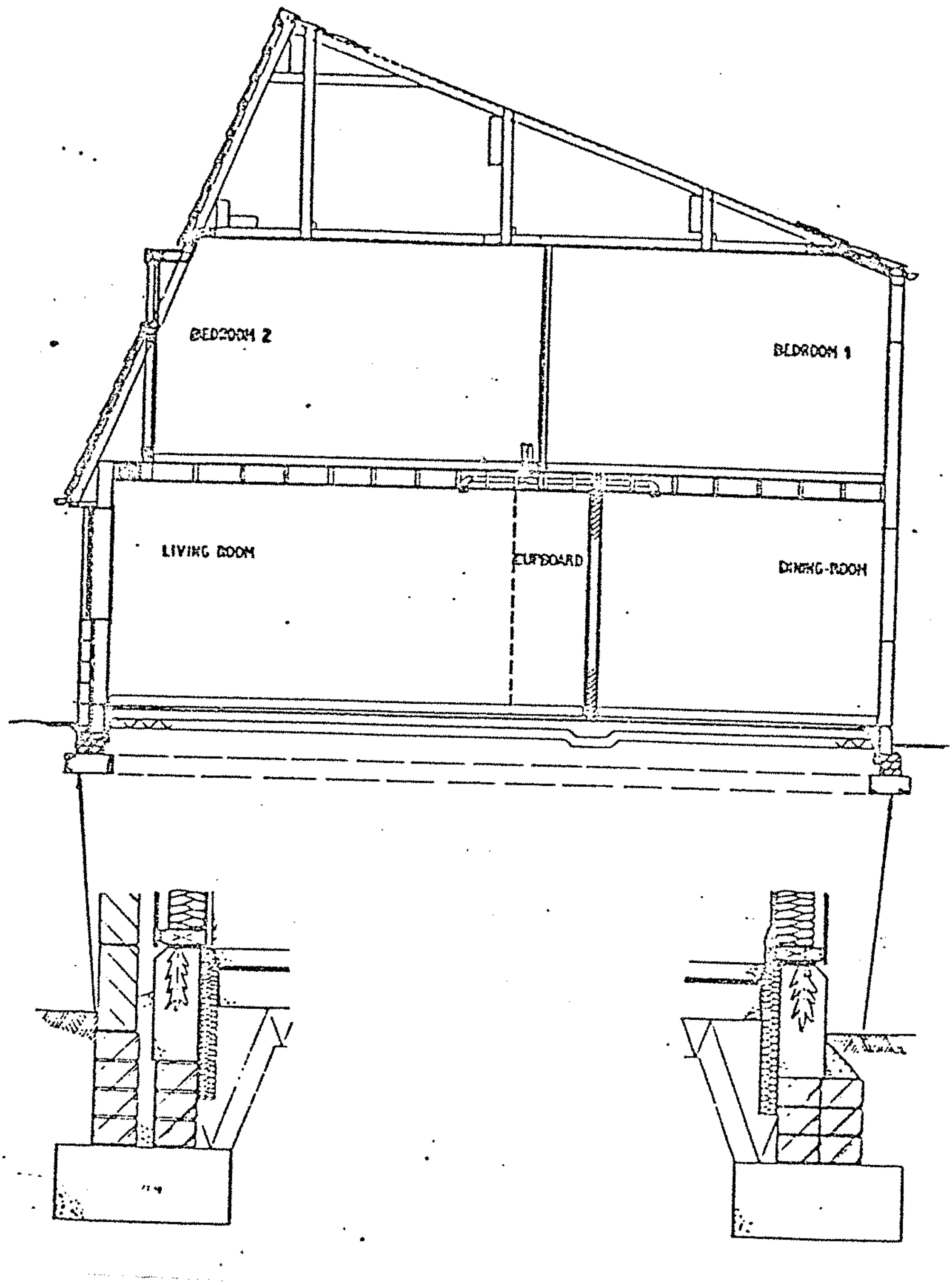


FIGURE A.6.3a. - SITE AVERAGE TOTAL ENERGY CONSUMPTION

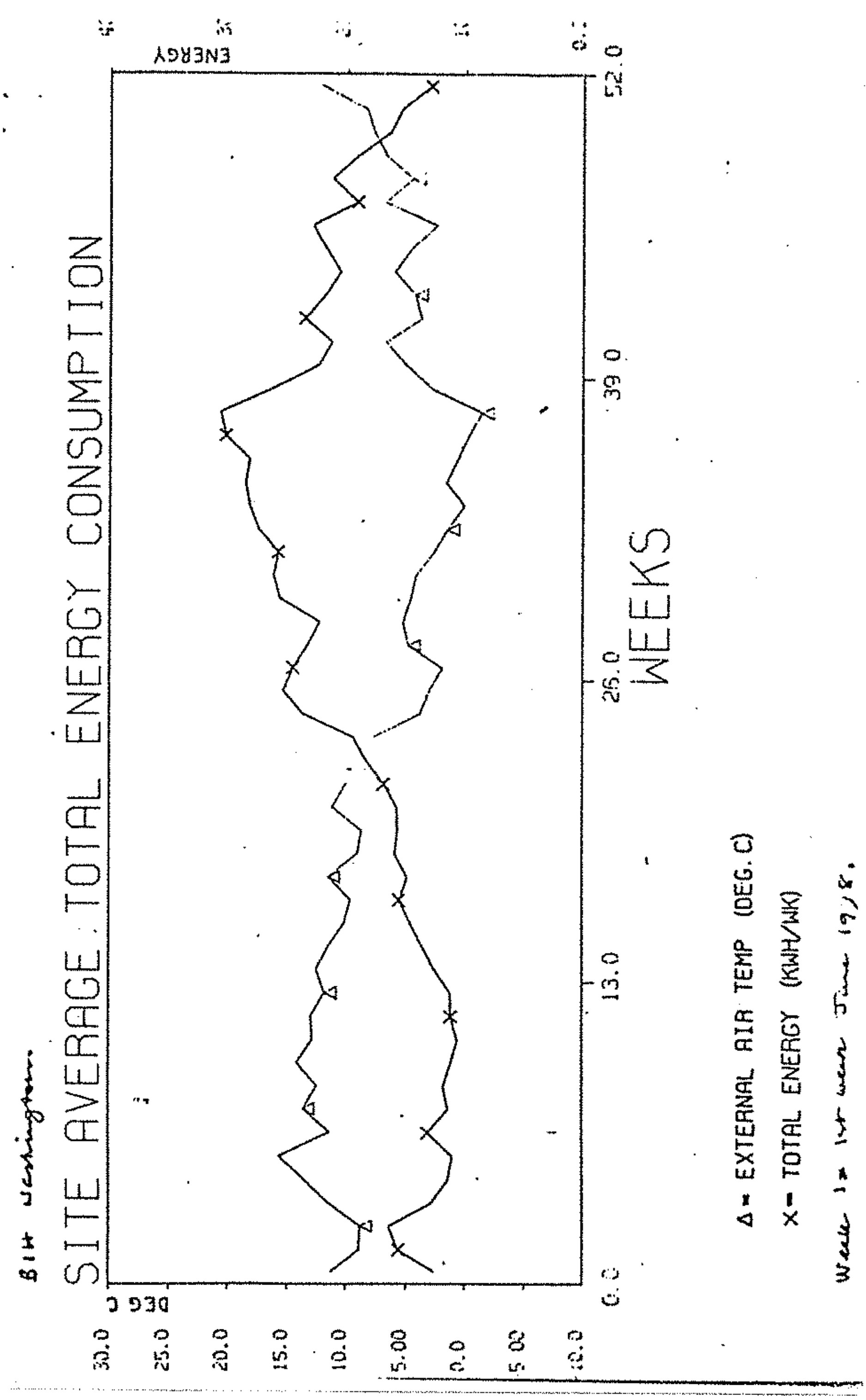
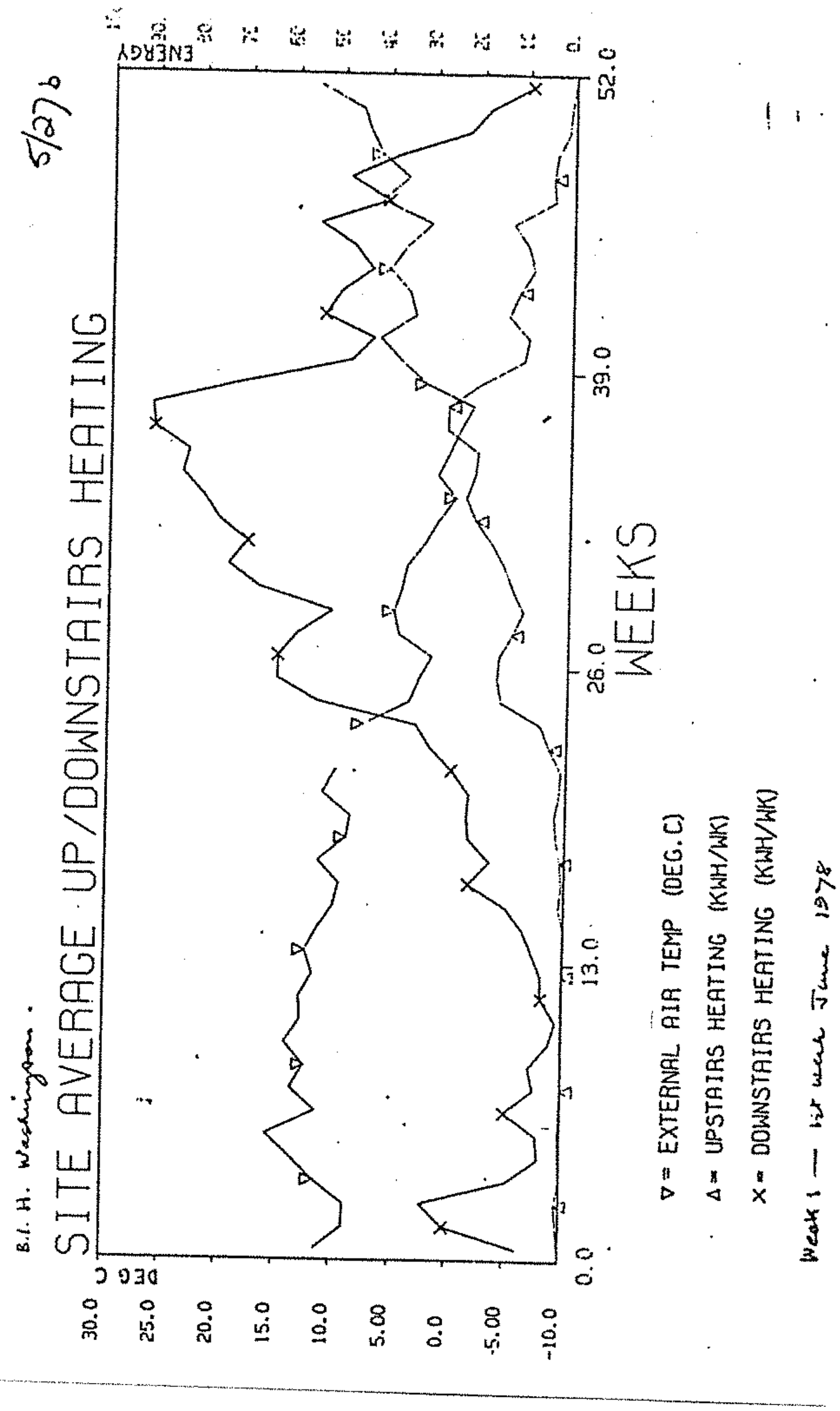


FIGURE A.6.3b. - SITE AVERAGE UP/DOWNSTAIRS HEATING



A/7. ABERTRIDWR

1. Abertridwr is a former mining village about 10 miles north ‹ Cardiff, and about 200m above sea level, on a steep site expos‹ to west and south-west winds.

Dwellings

2. The project involves 39 dwellings out of a new estate ‹ about 100 for the United Kingdom Housing Association, started : 1976 and completed in 1980 after contractual delays. They a: all 4-person terrace houses in wide fronted split-level forı built along the contours of the 1 in 3 slope (Figure A.7.1).

Construction

3. The control houses are of cavity wall construction with ‹ insulating block inner lead, to meet the 1975 Buildiı Regulations. Test houses have 20mm of urethane foam insulati‹ in a sandwich board dry lining, the site being too exposed ‹ allow cavity filling. Test houses also have 100mm of gla: fibre in roofs (control houses 50) and both perimeter and sl‹ edge insulation to floors. Calculated heat losses of te: houses were thus 23% less than those of control houses. Desi‹ is by the National Building Agency (Wales).

Heating systems - test houses

4. The test houses have gas fired radiator heating system: specially designed by British Gas and based on 8.2 kW boiler: which serve domestic hot water as well. Initially the onl radiator upstairs was one on the landing.

Control houses

5. The control houses have whole-house central heating, with larger (14.7kW) boiler. These seem to be quite satisfactory One of the objects of the experiment was to test in 'real conditions a heating system smaller and cheaper than woul normally be installed in such houses, especially at such ‹ exposed site. In fact the test house systems cost about £2C less per house. All radiators have TRV's, and the whole systen are controlled by room thermostats in living rooms.

Monitoring

6. Up until Autumn 1980 only 11 dwellings were occupied due t contractual delays. By this time 1 whole year's data had bee collected from 7 test and 4 control houses. Unfortunately thi date will not yield useful comparisons as the control houses use considerably more energy for all purposes. Monitoring c subsequent years provided a comprehensive data base from sophisticated logging system which measured:-

- temperatures in all rooms and loft spaces
- boiler performance (input and output)
- domestic hot water consumption
- cooking consumption whether gas or electric
- other electricity
- wind speed and direction, external temperature and direct an diffuse solar radiation.

7. Most measurements are taken at 12 second interva continuously, averaged and logged every 5 minutes, and verifi by a computer on site. The data is then distilled (numericall and stored for later analysis.

Discrete experiments

8. Site delays provided some time for additional experiments the site. These included studies of heating systems temporarily unoccupied houses, and of the temperatures reached the same house under solar gain only. As well as these, thr separate series of air leakage and air infiltration measuremen have been conducted by BRE and British Gas, together wi thermographic surveys to reveal hidden deficiencies in structur insulation. The 'unheated house' tests showed, for the peri tested:

- temperature effects, by room, of solar gain
- whole-house solar gains
- rates of cooling after heating shut down, and subseque recovery.

9. The air tests showed that in general the houses are qui tight, but leakage increased materially during the first year occupation, before settling down. The adventitious leakag seems to occur mainly at front door (warping), skirtings (wa leakage) and via internal service ducts, ceiling cracks and lo hatches. Air change rates are excessive in some spaces that not need it, and inadequate in some which do, so that in practi energy was probably being wasted unnecessarily. Stack effec in cold weather, is more significant in these houses than houses of conventional internal height. It has the useful rol of distributing heat, however, but in some conditions is ove ridden by cross ventilation. The opening of windows has dramatic effect on ventilation and some far less crude control i needed. An initial experiment with trickle ventilators wa conducted during the final winter and may be extended as additional project thereafter. Wind direction has a marke effect on the ventilation rates due to leakage, as also doe windspeed.

10. Thermographic surveys showed up cold spots in externa walls, caused by some cavity bridging, by battens incorporated i the dry lining construction, by insulation left out b contractors, and by cold draughts through walls of porous blocks with the (inevitable) air passages at joints as well.

11. Two or three houses suffered some condensation and moul growth on bedroom window reveals - including both test an control houses. This is thought to be attributable to combination of:

- cold air in the wall cavities, closed by a PVC box sectio component with little insulating value
- inadequately heated bedrooms, for economy's sake
- rapid cooling when windows were left open.

All such explanations are of course speculative. Trick ventilators are being put in these rooms in the hope they wi cure the condition.

12. Figure A.7.2 is a combination diagram by UWIST which self-explanatory. Similar diagrams from other houses fail show this dramatic fall in bedroom temperatures brought about l opening all the bedroom windows (the central heating downstai and on the landing makes no apparent difference to the bedroom against that amount of ventilation). Other houses where bedro windows are not thus flung open maintain bedroom temperatures lower than 14degC. This comparison illustrates the extre sensitivity of low energy houses to over-crude ventilati control, and helps to make the case for trickle ventilator

FIGURE A.7.1. - ABERTRIDWR - 4 PERSON SPLIT LEVEL TERRACE HOUSE

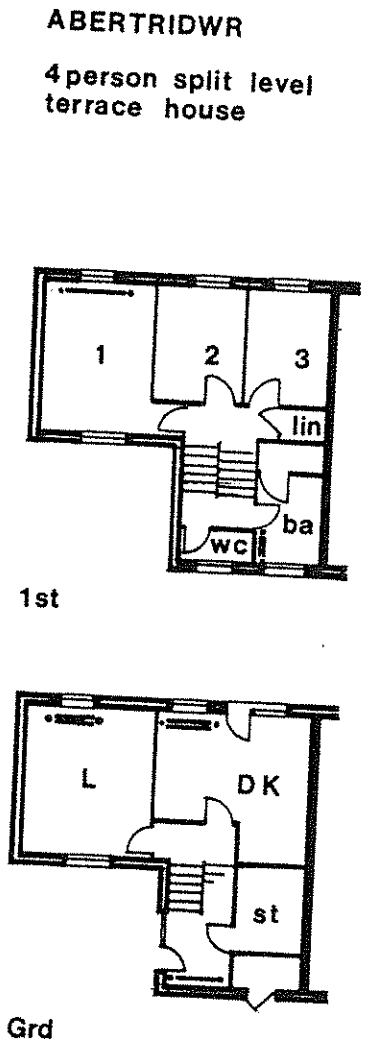
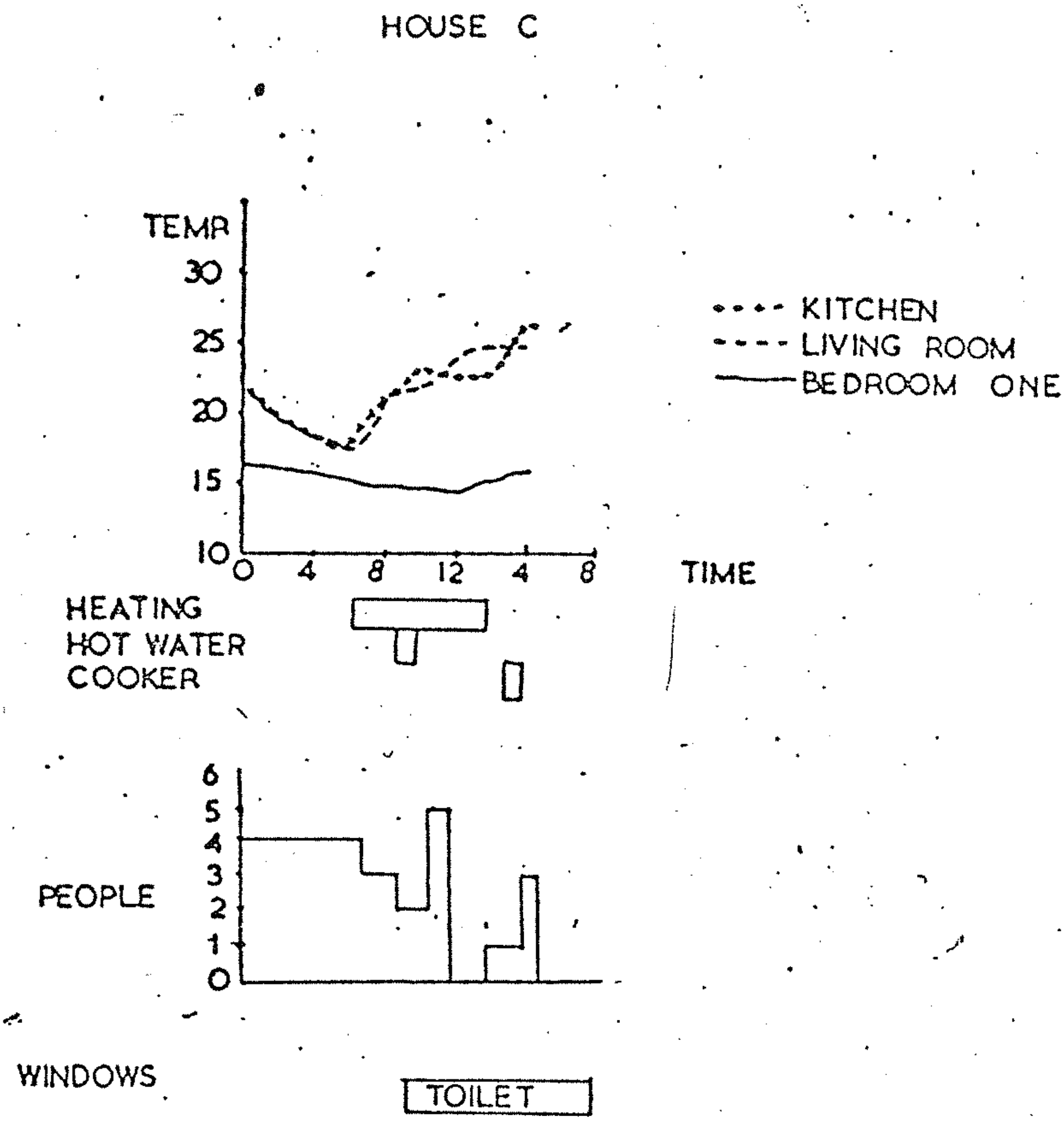


FIGURE A.7.2. - COMBINED DATA



A/8. BO'NESS

1. The Bo'ness project occupies Phase 1C of the Scottish Specia Housing Association's Kinneil Estate on the outskirts of Bo'nes of the Firth of Forth. The project houses lie between 54 an 75m above sea level, on a north-facing slope (Figure A.8.1).

Dwellings

2. 42 houses are involved, 23 control and 19 test. A site plar reveals the variety of houses - which was to complicate the task of comparison greatly. Furthermore, while there are both terraced and detached houses, some of the latter are so close together as to make difficult the estimation of the U-values of their adjacent walls. Furthermore, there are three distinct house types, each appearing in mid-terrace, end-terrace and detached form, and (with one exception) in test and control versions as well, giving 17 different values for AU. It was not possible to match small subsets based on house type only, as household characteristics would also differ. So the monitoring team (Heriot Watt University) sensibly lumped all of the test and control houses together in crude groups, for analyses on the (weighted) means of their thermal characteristics, namely 264 and 335 watts/degC respectively. Thus the test houses were 'improved' to the extent of some 37% (at the air change rates assumed).

Construction

3. All the houses are of 'no fines' concrete wall construction, rendered externally (and suspended timber floors). Control house walls have dry lining and 13mm polystyrene insulation. Roofs have 50mm glass fibre insulation above ceilings and a further 12mm insulating underslating beneath tiles. Test houses have 100mm insulation above ceilings, 50mm under ground floors, and a dry lining of 25mm polyisocyanurate board bonded to plasterboard. All windows are single glazed.

Heating systems

4. Electric block storage/warm air heating systems are incorporated in all houses, the test houses having a smaller block. (Capacity 47 kWh as opposed to 55kWh). In all houses the warm air supply is distributed to the ground floor only, but with the Hall register sized to heat the first floor rooms. The fan operations are controlled by time-clocks and living-room thermostats. Hot water is provided by a 3 kW immersion heater in a 136 litre tank in a cupboard off the landing.

5. Very few households used only the central heating - supplementary heat was achieved by electric, LPG and paraffin fires (in that order of popularity). The reasons appear to have been (and here the order is insignificant):

occasional heating needed upstairs
radiant source wanted in living room
stored charged of heat inadequate for whole day (mostly in test houses)
high cost of electric heating

One household, however, has managed to heat the whole house its satisfaction using only the system provided, but has not y been forthcoming about the method.

6. It was also noted (in one of Heriot Watt's reports) that large number of time-clocks and thermostats were said (tenants) to be broken. However, the majority of tenants seem to be 'fairly satisfied' with the heating in general, thou nearly half were dissatisfied by its performance in seve weather. It is interesting to note that thermostat settin were on average higher in the control houses, but whole hou temperatures were higher in test houses. The former perha reflects the larger capacity of control house storage system which would deliver heat for longer on a high 'stat setting Test houses could be expected to be warmer nevertheless, becau internal convection would heat bedrooms more effectively, wi their superior insulation.

Consumptions

7. Table 1.1 summarises metered electricity consumptio recorded over a year. These are interpreted (figures brackets) in terms of their estimated heat input to the house The latter have been derived here according to SBRE's metho rather than Heriot Watt's, purely so as to match equivale figures from other projects. The difference arises in t proportion of power assumed as realised in the form of heat. preference between the two methods is to be inferred - neith set of assumptions is provable at present. To the measur figures are added estimates for metabolic and solar gains. Mo representative figures for these gains should be available in d course from site measurements. The purpose of making su assumptions at this stage is to complete an estimate of tot heat losses through the heating season, to compare with appare mean house temperatures and calculated rates of heat loss.

Temperatures

8. Fragmentary graphs of mean whole-house temperatures a available. These graphs suggest mean temperatures of 13.5 ar 15degC, at external temperature of 6degC. These show how me internal temperatures are affected by external conditions, ar test houses consistently warmer than control houses. Bot phenomena are inevitable from such a comparison, given the heating and control systems. Whole-house temperatures refle the heated ground floor rooms, and the first floor rooms warme by convected heat from the Hall, with only the minimum c control. Except when modified by the use of supplementar heaters, the latter will rest at an arbitrary temperature whic is a balance between convective heat from downstairs and th various losses from these rooms to outside. Convectiv transfers will tend to be greater on colder days, due t increased stack effect, but there is probably more likeliho also of extra upstairs heating being used at such times, and i addition there is plenty of scope for households to modify suc transfers - if they understand what they are doing - by openin or shutting doors (see Plymouth project (above).

9. It seems that the mean difference in whole-house temperatur is about 1.5degC with a control house mean winter inside/outsi difference of 7.5degC. The approximate effect of this 2 increase, upon the assessment of the comparison is indicated Table 1.1 which sums up all the (recorded or estimated) he inputs to the mean of each group of houses. To represent pari in internal temperatures, it is necessary to increase the tot heat losses from the control houses by this ratio between the mean inside/outside temperature differences. Such a calculati serves to indicate that on a basis of temperature parity t control houses would have used some 10.5% more energy, or extra 2515kWh. But this difference between the two is far sho of what the calculated heat losses and rates of ventilati suggest might have been realised - namely 8825 kWh. Clear there is at least one other factor, other than temperature having a large influence. The above calculations are based an extremely weak estimate of the size of the temperatu difference between the two graphs. In due course data will available measured in both groups continuously over a heati season, and the above very tentative appraisal can perhaps revised. But even if the temperature difference between the t groups were 2degC, the total consumption difference (temperature parity) would still only be about 16%.

Heriot Watt reports

10. The University have so far presented a two-part Inter Report and another in the form of an MSc thesis by one of t team. The above has drawn on both sources. The thesis ((Capper) includes a proposal for analysis of a broad spectrum reliably measurable data which has a statistically significa effect on energy consumption. This technique (multip regression analysis) avoids drawing conclusions affected either socio-economic characteristics of householders, or non measurable factors of building physics. The former usual occur as minor sample biases, and the latter are notorious unreliable (e.g. U-values are affected by weather). Suc analysis may offer a useful means of appraising such projects this, where samples are small and full of variety.

11. However, if results are influenced by strong difference between the groups in the thermal performance of houses a heating systems together, these will not be revealed. T University suspect such an influence here, in respect of t efficiency of the heating controls - which may be leading inordinately high ventilation heat losses to relieve over heating. While most of the test house tenants have bee dissatisfied with their heating and have found it ofte inadequate, one tenant who has appropriate technical knowled has managed to make his work well. This suggests there is ro for improvement which might affect the comparisons betwee groups.

12. Other possible factors may include:

extra ventilation necessary for paraffin and LPG heaters used more in test houses

under-performance of wall insulation due to poor workmanshi or difficulty with materials effect of thermostats and time-clocks reported to be broke

unequal (between groups) heat losses from under-floor wa
air ducts - greater in test houses with colder crawl-space

heat loss calculations inaccurate due to colder (test hous
crawl-spaces

differing responses to solar gain, due to differences
thermal capacity.

The above list is entirely speculative, and implies no order
likelihood nor of size of effect.

FIGURE A.8.1. - BO'NESS - 6 PERSON DETACHED HOUSE

BO' NESS

6 person detached house